

BRIEF REPORTS

Late Positive Potential to Appetitive Stimuli and Local Attentional Bias

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Predicated on the idea that positive affects high in approach motivation are crucial in goal-directed behaviors, research has found that these positive affects cause narrowed attention. The present research was designed to investigate a possible neurophysiological underpinning of this effect. Previous research has suggested that the late positive potential (LPP) of the event-related brain potential is increased by emotionally arousing stimuli because of the attention-grabbing nature of such stimuli. Other research has suggested that left prefrontal cortical regions are associated with narrowed attention and approach-motivated affect. Integrating these two lines of evidence, the present research examined LPPs to appetitive versus neutral pictures and assessed the relationship of these LPPs to local versus global attentional bias following the picture primes. Results revealed that appetitive in comparison with neutral pictures evoked larger LPP amplitudes bilaterally over central and parietal regions and asymmetrically over frontal regions. Moreover, these LPP amplitudes to appetitive pictures predicted greater locally biased attention caused by the appetitive pictures. These results provide the first evidence that LPPs are associated with the local attentional bias induced by appetitive motivation.

Keywords: local–global attention, approach motivation, late positive potential, event-related potentials, asymmetrical frontal cortical activity

Decades of research has suggested that positive emotions “broaden the scopes of attention, cognition, and action, widening the array of percepts, thoughts, and actions presently in mind” (Fredrickson & Branigan, 2005, p. 315). In support, research found that positive affect increases flexible and inclusive categorization, unusualness of word association, breadth of social categorization, creativity, and openness to information (see the review by Isen, 2004). More recently, investigations have shown that positive affect causes a broadening of the scope of attention (Fredrickson & Branigan, 2005; Rowe, Hirsh, & Anderson, 2007). This research used gift, film clip, and memory manipulations to induce positive affect, and the positive affect induced is likely one low in approach motivational intensity. That is, the positive affects were irrelevant to goals or occurred after goal accomplishment.

Positive affects, however, vary in the degree to which they are associated with approach motivation, and positive affects of different motivational intensities have distinct effects on attention and cognition. Low approach-motivated positive affects cause broadening of cognition and attention (Fredrickson & Branigan, 2005; Gable & Harmon-Jones, 2008a; Rowe et al., 2007), presumably because these positive affects suggest a stable and comfortable

environment (Fredrickson & Branigan, 2005). In contrast, high approach-motivated positive affects cause narrowing of cognition and attention (Gable & Harmon-Jones, 2008a; Harmon-Jones & Gable, 2009), presumably because narrowed processes assist in the shutting out of irrelevant stimuli and cognitions as organisms approach and attempt to acquire desired objects (Harmon-Jones & Gable, 2008).

Past experiments on positive affect and attentional scope used local–global bias tasks to assess attentional scope. One prominent measure of attentional scope is the Navon (1977) letters task (for a review, see Kimchi, 1992). As is shown in Figure 1, the large letters are made up of closely spaced local letters, and the participant’s task is to identify a specified letter in the array. The letter to be identified is either a small (local) one or large (global) one. Hundreds of studies using this task have revealed that individuals respond more quickly to global letters than to local letters under neutral conditions (Kimchi, 1992). Our past research has found approach-motivated positive affect to slow global reactions, or both slow global reactions and speed local reactions (Gable & Harmon-Jones, 2008a; Harmon-Jones & Gable, 2009a). Similar effects emerged in research on arousing negative affect (Wachtel, 1968). These results suggest that it is the difference in attentional scope between affective and neutral states that is of importance; becoming less broad (or globally biased) or becoming more narrow (or locally biased) should confer similar advantages in adaptively responding to motivational stimuli.

The present experiment was designed to investigate a possible neurophysiological underpinning of the effect of approach-motivated positive affect on the narrowing of attention. The late positive potential (LPP), a component of the event-related potential (ERP) occurring between 300 and 1200 ms after stimulus

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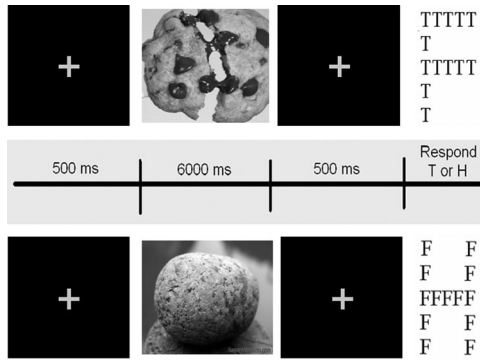


Figure 1. Example trial order and timing for appetitive and neutral pictures.

onset, is larger in amplitude to affective than to neutral stimuli, especially arousing affective stimuli (for reviews, see Keil et al., 2001; Olofsson, Nordin, Sequeria, & Polich, 2008). This LPP effect has been interpreted as reflecting motivated attention, or the reflexive engagement of attentional resources (Lang, Bradley, & Cuthbert, 1997). The LPP is likely driven by several structures, including the lateral occipital, inferior temporal, and medial parietal cortex (Sabatinelli, Lang, Keil, & Bradley, 2007) and the temporal parietal junction and lateral prefrontal cortex (Nieuwenhuis, Aston-Jones, & Cohen, 2005).

Some studies have found that the LPP is hemispherically lateralized over the frontal cortex to affective stimuli. For instance, Cunningham, Espinet, DeYoung, and Zelazo (2005) found that “good” words evoked a greater left frontal LPP, whereas “bad” words evoked a greater right frontal LPP. Van de Laar, Licht, Franken, and Hendriks (2004) found that pictures of drug stimuli evoked greater LPPs over the left frontal cortex in recovering drug addicts than in controls. Graham and Cabeza (2001) found that correctly recognized happy faces evoked greater LPPs over the left than right frontal cortex. Lateralization of the LPP over the frontal cortex is consistent with other research using multiple methods that has demonstrated that the frontal cortex is asymmetrically involved in emotive processing (for reviews, see Harmon-Jones, 2003; Pizzagalli, Shackman, & Davidson, 2003). Specifically, the left prefrontal cortex is involved in approach motivational processing, which is often associated with positive emotions such as desire (Gable & Harmon-Jones, 2008b) and with negative emotions such as anger (Harmon-Jones, Lueck, Fearn, & Harmon-Jones, 2006; van Honk & Schutter, 2006). In contrast, the right prefrontal cortex is involved in withdrawal motivational processing, which is often associated with emotions such as fear (Buss et al., 2003).

Whereas many studies have found LPP amplitude to differ between neutral and affective stimuli, only a few of these studies have found a hemispheric lateralization of LPP over frontal regions. Experiments that have found frontal hemispheric lateralizations have used stimuli that were uniform and evoked strong appetitive reactions (van de Laar et al., 2004), or they have used idiographically defined stimuli (Cunningham et al., 2005). The use of only one type of appetitive stimuli (or the use of idiographic methods) may have kept participants’ approach motivation relatively high to all stimuli. Mixing different types of appetitive stimuli may weaken the approach motivational impact of the stimuli, because

all individuals may not find all types of appetitive stimuli approach motivating. Because of these past findings, we use only one type of appetitive stimuli in the current experiment.

In addition to previous work associating the LPP with motivated attention, other work has found that local attentional processes are more lateralized to the left hemisphere than to the right hemisphere (Hübner & Volberg, 2005). Asymmetrical attentional processing could be facilitated by other asymmetrically related processes, specifically, approach motivational processes. That is, appetitive processing, which is associated with the left prefrontal cortex and lateralized frontal LPPs, may also facilitate the relative narrowing of attention. This prediction is consistent with findings that approach emotional states related to left frontal cortical activation facilitate cognitive processes engaged by the same region (Gray, 2001; Gray, Braver, & Raichle, 2002).

The Present Experiment

On the basis of the above, several hypotheses were generated. First, on the basis of the idea that LPP amplitude indexes motivated attention, we predicted that appetitive stimuli would cause greater LPP amplitudes (over several regions) than would neutral stimuli. Second, because motivated attention may underlie the effect of appetitive stimuli on narrowed attention, we predicted that LPP amplitude would relate to greater narrowing of attention following appetitive picture primes. Third, on the basis of past research suggesting the frontal cortex to be asymmetrically involved in approach motivational processes, we predicted LPPs to appetitive pictures would be larger in the left than the right frontal cortex, and the left LPP should be larger to appetitive pictures than to neutral pictures. Finally, because the left hemisphere is more involved in both approach motivation and local attention, we predicted that the left rather than the right frontal LPP should predict more local attentional focus following appetitive primes.

Method

Thirty (11 women) unselected right-handed introductory psychology students participated for course credit (gender exerted no significant effects). After providing informed consent, electroencephalograph (EEG) electrodes were applied. Because of equipment malfunction, Site F3 on 1 participant was not included in analyses.

Participants viewed 64 pairs of pictures preceded by six neutral practice trials. Each trial consisted of a fixation cross (500 ms) followed by an appetitive picture (desserts) or by a neutral picture (rocks; each for 6 s) used in previous research (Gable & Harmon-Jones, 2008a, 2008b; Harmon-Jones & Gable, 2009). Pictures were matched for color, brightness, and object size. After the picture and another fixation cross (500 ms), a letters picture was displayed until the participant responded. If the participant did not respond within 5 s, the next trial began (see Figure 1). Intertrial interval varied between 18 and 20 s in order to allow participants time to recover between the reaction time (RT) task and affective stimuli.

Letters pictures were based on the Navon (1977) letters task and were used to assess local versus global attentional focus. Each picture was a large letter comprising smaller letters. The large letters were made up of five closely spaced local letters on each vertical or horizontal line (e.g., an *H* of *Fs*). Participants were asked to quickly identify whether the picture contained the letter *T*

or the letter *H* by pressing corresponding buttons. Global targets were those in which a *T* or an *H* comprised smaller letter *L*s or *F*s. Local targets were those for which a large *L* or *F* comprised smaller *T*s or *H*s. Faster responses to the large letters indicate a global bias, whereas faster responses to the small letters indicate a local bias. Thirty-two local trials and 32 global trials were randomly presented.

After picture pairs, participants viewed the appetitive or neutral pictures again (3 s each) and indicated their pleasure (1 = *very pleasing*, 9 = *very unpleasing*) and arousal (1 = *exciting*, 9 = *calm*) on the Self-Assessment Manikin (Bradley & Lang, 1994). Desire for each picture was also measured (1 = *really desired*, 9 = *did not desire*). Consistent with ratings from previous studies (Gable & Harmon-Jones, 2008a, 2008b), participants rated the appetitive pictures more pleasing ($M = 3.49$, $SE = .18$), arousing ($M = 5.15$, $SE = .35$), and desirable ($M = 4.15$, $SE = .28$) than neutral pictures ($M = 5.10$, $SE = .23$; $M = 7.45$, $SE = .26$; $M = 7.07$, $SE = .31$, $ps < .0001$).

EEG was recorded with 22 tin electrodes in a stretch-lycra electrode cap. We focused our data acquisition on the frontal sites because of our interest in frontal asymmetry. All sites were referenced online to the left earlobe; offline, data were referenced to linked ears. Electrode impedances were under 5000 Ω ; homologous sites were within 1000 Ω of each other. Signals were amplified with Neuroscan SynAmps2, bandpass filtered (0.05–500 Hz), notch filtered (60 Hz), and digitized at 2500 Hz. Artifacts (e.g., horizontal eye movements and muscle) were first removed by hand. Then, a regression-based eye movement correction was applied (Semlitsch, Anderer, Schuster, & Presslich, 1986).

The data were epoched for 100 ms before picture (appetitive or neutral) onset until 1200 ms after picture onset and were filtered with a low pass of 35 Hz. Aggregated waveforms for each picture type were created and baseline corrected using the prestimulus activity. LPP amplitude was measured as the mean EEG activity within a window of 500–1000 ms, on the basis of visual inspection and consistent with previous research investigating frontal lateralized LPPs (Graham & Cabeza, 2001; van de Laar et al., 2004).

To limit the number of statistical tests, we focused our results on testing a priori predictions. Consequently, no controls for Type 1 error were used (Keppel & Zedeck, 1989). RTs to local and global targets were logarithmically transformed. Incorrect responses (6% of the sample) and those more than 3 standard deviations from the mean (0.6% of the sample) for each stimulus were removed.

Results

Local–Global Reaction Times

The RT results revealed that appetitive stimuli, in relation to neutral stimuli, sped detection of local stimuli and slowed detection of global stimuli, replicating previous experiments (Gable & Harmon-Jones, 2008a; Harmon-Jones & Gable, 2009). These effects were revealed in a significant 2 (appetitive or neutral picture) \times 2 (local or global target) within-subjects analysis of variance (ANOVA), $F(1, 28) = 32.39$, $p < .0001$, $\eta_p^2 = .54$. Follow-up tests revealed that RTs to local targets were faster after appetitive pictures ($M = 6.62$, $SE = 0.04$) than after neutral pictures ($M = 6.69$, $SE = 0.04$), $t(29) = 4.66$, $p < .0001$, $d = 0.62$. In contrast, RTs to global targets were slower after appetitive

pictures ($M = 6.63$, $SE = 0.04$) than after neutral pictures ($M = 6.58$, $SE = 0.04$), $t(29) = 2.36$, $p = .03$, $d = 0.31$. After neutral pictures, participants responded faster to global targets than to local targets, $t(29) = 4.94$, $p < .0001$, $d = 0.65$. This finding is consistent with findings in previous studies (Gable & Harmon-Jones, 2008a; Harmon-Jones & Gable, 2009a; Kimchi, 1992); participants generally show a global bias on this task. After appetitive pictures, RTs did not differ between global and local targets, $t(29) = 0.49$, $p = .62$, $d = 0.07$.

LPP Amplitudes

Replicating past work, we found that LPP amplitudes were greater after appetitive pictures than after neutral pictures at mid-line frontal, central, and parietal sites (all $ts > 3.81$, $ps < .001$, $ds > 0.50$). Also consistent with past research, appetitive pictures produced larger LPP amplitudes at lateral central and parietal sites (C3, C4, P3, and P4; all $ts > 3.40$, $ps < .01$, $ds > 0.44$).

For left lateral frontal sites (F3, F5, and F7), LPP amplitudes were greater after appetitive pictures than after neutral pictures (all $ts > 3.47$, $ps < .001$, $ds > 0.45$). In contrast, at right lateral frontal sites, no consistent differences between appetitive and neutral pictures were found. For instance, at one right frontal site, F4, LPP amplitude was greater after appetitive pictures than after neutral pictures, $t(29) = 3.19$, $p = .003$, $d = 0.42$. But at another right frontal site, F8, LPP amplitude was greater after neutral pictures than after appetitive pictures, $t(29) = 2.23$, $p = .03$, $d = 0.29$. And finally, at the other right lateral frontal site, F6, no picture type differences were found, $t(29) = 0.75$, $p = .46$, $d = 0.10$ (see Figure 2).

Next, we compared LPPs to appetitive pictures between the two hemispheres. LPPs to appetitive pictures were greater in the left hemisphere than in the right hemisphere for all lateral–frontal sites (all $ts > 2.19$, $ps < .05$, $ds > 0.29$; see Table 1). In other regions, no hemispheric differences were observed. These results are conceptually consistent with the results of van de Laar (2004) and of Cunningham et al. (2005).^{1,2}

Correlations Between LPP Amplitudes and Local–Global Motivated Attentional Bias

Controlling for neutral pictures RTs. Because of our interest in the effects of appetitive motivation on attentional bias, we examined correlations between LPP amplitudes to appetitive pictures and RTs to local (and then global) targets after appetitive pictures, controlling for RTs to local (global) targets after neutral pictures. These controls were implemented to test whether the predicted correlations were significant after eliminating variance due to RTs to neutral stimuli.

¹ Despite three previous studies finding frontal LPP differences, some studies failed to report frontal LPP differences between stimuli. Many of these studies used a whole-head average reference. This type of reference can eliminate frontal asymmetry effects when EEG/ERP signals are more prominent in posterior regions, as they are with the LPP (Hageman, 2004).

² Some past research has revealed ERP differences between affective and neutral stimuli in the 100- to 230-ms range over posterior regions (Olofsson et al., 2008). We did not observe such effects in our data, perhaps because we did not include electrodes at which these effects are maximal.

Lateral Frontal Late Positive Potentials to Pictures

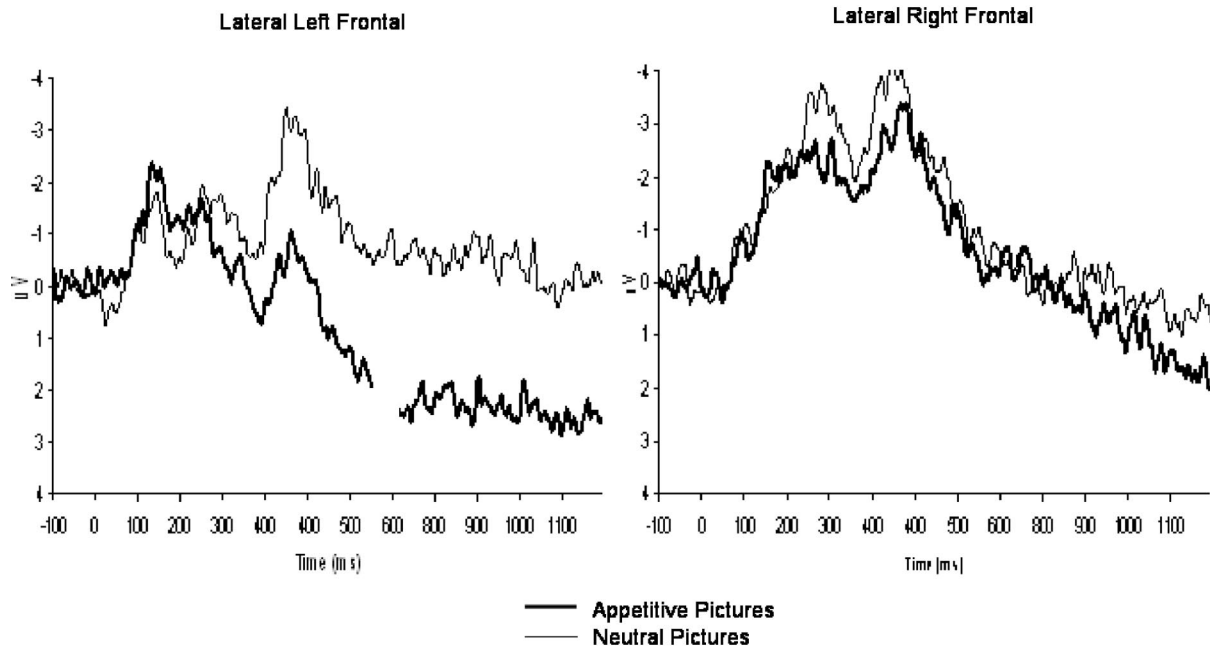


Figure 2. Left (F5) and right (F6) lateral LPP amplitudes across picture type.

At midline sites, LPPs to appetitive pictures significantly predicted faster RTs to local targets after appetitive pictures, controlling for RTs to local targets after neutral pictures (partial $r_s > -.49$, $p_s < .01$). Similar results also occurred at the frontal sites, particularly left frontal sites (see Table 1). Regarding global bias, LPP amplitudes at midline and frontal sites did not relate to global target RTs after appetitive pictures (partial $r_s < -.34$, $p_s > .07$).

Table 1
Means (and Standard Deviations) of LPP Amplitudes (μV) for Picture Type Across EEG Sites and Partial Correlations of LPP Amplitude and Local RT Following Appetitive Primes, Controlling for Local RT Following Neutral Primes

Site	Picture type		Partial r_s of LPP with local bias after appetitive
	Appetitive	Neutral	
F3	1.86 (4.79) ^{aa}	-0.74 (3.73) ^{ba}	-.54**
F4	0.86 (3.22) ^{ab}	-0.85 (3.19) ^{ba}	-.49*
F5	1.91 (4.67) ^{aa}	-0.83 (3.95) ^{ba}	-.50*
F6	-0.86 (3.22) ^{ab}	-0.67 (2.70) ^{aa}	-.36
F7	1.26 (4.58) ^{aa}	-1.40 (4.47) ^{ba}	-.35
F8	-2.06 (3.93) ^{ab}	-0.61 (3.44) ^{ba}	-.11

Note. LPP = late positive potential; EEG = electroencephalogram; RT = reaction time. The first two columns of numbers are means (SDs) of LPP amplitudes (μV) for picture type across EEG sites. Different superscript letters (a, b) indicate differences at $p < .05$. The third column is the partial correlation of LPP amplitude and local RT following appetitive primes, controlling for local RT following neutral primes. For these, * = $p < .01$; ** = $p < .001$.
^a Indicates comparisons between picture type (row). ^b Indicates comparisons between corresponding left and right sites (column; e.g., F3/F4).

Controlling for neutral picture LPPs. We next examined correlations between LPP amplitudes to appetitive pictures and RTs to local (and then global) targets after appetitive pictures, controlling for LPPs to neutral pictures. These controls were implemented to test whether the appetitive LPP still predicted appetitive local bias after eliminating variance due to LPPs to neutral stimuli. On the basis of the previous results, we created a single criterion variable to capture local attentional bias induced by appetitive pictures (local targets after appetitive pictures minus local targets after neutral pictures).

At midline sites FZ and CZ, LPPs to appetitive pictures predicted faster RTs to local targets after appetitive pictures, controlling for LPPs to neutral pictures (partial $r_s > -.38$, $p_s < .05$). At PZ, the partial correlation was nonsignificant (partial $r = -.32$, $p = .12$).

At left frontal sites and one right frontal site, LPPs to appetitive pictures predicted faster RTs to local targets after appetitive pictures, controlling for LPPs to neutral pictures, (partial $r_s > -.37$, $p_s < .05$). Other lateral right frontal sites produced nonsignificant effects (partial $r_s < -.20$, $p_s > .31$). Regarding global bias, LPP amplitudes at midline and frontal sites did not relate to global target RTs after appetitive pictures (partial $r_s < -.24$, $p_s > .22$).

Correlations Between Lateral Frontal LPP Amplitudes and Local Attentional Bias

The above results suggest that the LPP at midline and frontal sites correlated with greater local bias following appetitive pictures. Next, we wanted to test whether left frontal LPP amplitudes predicted more of this local attentional bias than did right frontal LPPs. Local attentional bias induced by appetitive pictures was

captured with a difference score of local targets after appetitive pictures minus local targets after neutral pictures.

Controlling for right frontal appetitive LPPs. Greater left LPP amplitudes to appetitive pictures predicted faster RTs to local targets after appetitive pictures (difference score), controlling for right LPP amplitudes to appetitive pictures (all partial $r_s < -.40$, $p_s < .05$). In these regressions, right LPP amplitudes to appetitive pictures did not relate to RTs to local targets after appetitive pictures (partial $r_s < -.20$, $p_s > .32$).

Controlling for left frontal neutral LPPs. Left appetitive LPP amplitudes predicted faster RTs to local targets following appetitive pictures, controlling for left LPP amplitudes to neutral pictures (all partial $r_s < -.37$, $p_s < .05$).

These results are consistent with the prediction that the local bias induced by appetitive stimuli is more strongly associated with the left frontal LPP (in comparison with the right lateral LPP) to appetitive pictures (in comparison with neutral pictures).

Discussion

Replicating past research, we found that appetitive stimuli, in comparison with neutral stimuli, evoked greater LPPs (over several regions) and more narrowed attention. Also, LPP amplitudes were consistently greater for appetitive pictures than for neutral pictures in left but not right frontal sites, and LPP amplitudes to appetitive pictures were greater at left frontal sites than at right frontal sites.

The novel contribution of the present research was that LPPs to appetitive stimuli related to local attentional bias. That is, greater LPPs to appetitive stimuli at several sites predicted more local attention following appetitive primes. In addition, left frontal LPP amplitudes to appetitive pictures predicted more local attention after appetitive pictures. In contrast, right frontal LPPs to appetitive pictures did not consistently predict such. These left frontal LPP and appetitive local bias relationships remained significant when controlling for right frontal LPPs and when controlling for left frontal LPPs to neutral pictures. Future work should test whether frontally lateralized LPPs are involved in similar or different psychological processes than are LPPs at other sites. Also, future work with larger electrode arrays should perform source analyses to uncover precise neural generators of the LPPs over the frontal cortex.

The present results are consistent with previous work on the LPP that has suggested that it is related to motivated attention and consistent with other work that suggests that local attentional processes are lateralized to the left hemisphere (Hübner & Volberg, 2005). The current results extend past work by finding that asymmetrical attentional processing is facilitated by other asymmetrical processes, specifically approach motivational processes (Gray, 2001; Gray et al., 2002). Appetitive processing, which is associated with the left prefrontal cortex, also increased locally biased attention.

We sought to examine positive approach motivational processes, because of the long-standing interest in positive affect and attentional breadth. Future studies should examine similar processes involved in negative affect and attentional breadth. Negative stimuli high in motivational intensity should evoke a relative narrowing of attention (Easterbrook, 1959; Mathews & Mackintosh, 2004), whereas negative stimuli low in motivational intensity

should evoke a relative broadening of attention (Gable & Harmon-Jones, in press).

In this article, we have explained our conceptual variables in terms of motivational intensity instead of arousal. Motivational intensity overlaps considerably with arousal. Self-reported arousal and sympathetic nervous system activation are both associated with motivational intensity (Lang et al., 1997). However, motivation is not isomorphic with arousal; arousal can be increased without increasing motivation. We recently completed an experiment in which arousal was manipulated through bicycling. Although the arousal manipulation increased subjective arousal and heart rate, it did not enhance attentional narrowing (Harmon-Jones, Gable, & Hobbs, 2009). In contrast, manipulating positive approach motivation by giving participants the expectancy to consume desirable desserts does enhance attentional narrowing (Gable & Harmon-Jones, 2008a).

The current experiment extends past research by incorporating models of motivation, the LPP, and local–global attentional bias. Our results provide the first evidence that LPPs are associated with the local attentional bias induced by appetitive motivation, and thus they suggest a new understanding of the relationships between properties of emotions and cognitive processes.

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