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Attitudes to the right- and left: Frontal ERP asymmetries associated with stimulus valence and processing goals

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We used dense-array event-related potentials (ERP) to examine the time course and neural bases of evaluative processing. Participants made good vs. bad (evaluative) and abstract vs. concrete (non-evaluative) judgments of socially relevant concepts (e.g., "murder," "welfare"), and then rated all concepts for goodness and badness. Results revealed a late positive potential (LPP) beginning at about 475 ms post-stimulus and maximal over anterior sites. The LPP was lateralized (higher amplitude and shorter latency) on the right for concepts later rated bad, and on the left for concepts later rated good. Moreover, the degree of lateralization for the amplitude but not the latency was larger when participants were making evaluative judgments than when they were making nonevaluative judgments. These data are consistent with a model in which discrete regions of prefrontal cortex (PFC) are specialized for the evaluative processing of positive and negative stimuli.
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It has long been noted that verbal reports of attitudes may provide only part of a larger more complex evaluative system (Greenwald and Banaji, 1995; Nisbett and Wilson, 1977), and for over a half century, social psychologists have turned to physiological methods to measure attitudes when "people won't say, can't say, or don't even know" (Cacioppo et al., 1994). Measures such as electrodermal activity (EDA) and facial electromyographic (EMG) recordings have shown that evaluative processing has clear autonomic correlates; both in providing a powerful input into evaluative processing and as an outcome of evaluative processing (e.g., Cacioppo and Petty, 1979; Dickson and McGinnies, 1966; Dysinger, 1931). More recently, however, technological advances such as the development of functional Magnetic Resonance Imaging (fMRI) and systems for recording dense-array electroencephalograms (EEG) and event-related potentials (ERP) have allowed for an unprecedented ability to examine the brain processes underlying evaluative judgments.

Using EEG, Cacioppo and colleagues identified a late positive potential (LPP) associated with the processing of valenced stimuli that are presented in an emotionally incongruous context. These LPPs are observed when participants see a negative stimulus in the context of positive stimuli, or when they see a positive stimulus in the context of negative stimuli. Moreover, the amplitude of these LPPs varies as a direct function of the degree of difference between the valence of the stimulus and the valence of the context in which it occurs. For example, when presented in the context of positive stimuli, a strongly negative stimulus will result in a larger LPP than a mildly negative stimulus (Cacioppo et al., 1994, 1996). This LPP associated with evaluative incongruity is widely distributed across scalp electrodes but is more pronounced over posterior (parietal) scalp regions than over frontal sites. There is also evidence that the amplitude of this posterior LPP is greater over the right hemisphere than over the left—for both positive and negative stimuli presented in an incongruous evaluative context (Cacioppo et al., 1996). Although the timing of the posterior LPP varies as a function of context, it typically begins around 500 to 600 ms after stimulus presentation. Showing evidence for a negativity bias, LPPs are typically larger for negative stimuli in a positive context than positive stimuli in a negative context (Ito et al., 1998a,b), and the degree of hemispheric asymmetry (right greater than left) is greater for these stimuli as well (Cacioppo et al., 1996).

Further, researchers using this paradigm have shown that the posterior LPP is evident both when participants are making evaluative and nonevaluative judgments, suggesting that evaluative incongruity may be detected automatically (Cacioppo et al., 1996; Ito and Cacioppo, 2000; see also Crites and Cacioppo, 1996). A centro-parietal LPP has also been observed using valenced stimuli presented in a random sequence, and again the amplitude was equally high for positive and for negative stimuli (Schupp et al., 2000). Schupp et al. (2000) did find, however, that the amplitude of the LPP was largest for stimuli that were the most arousing—presumably the stimuli with the greatest motivational relevance. This finding, together with the finding that the posterior LPP is not

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valence-specific, suggests that this LPP may not reflect the processing of evaluation per se, but rather may reflect detection of stimuli with motivational significance or downstream categorical processing of output from an evaluation system.

Despite the insensitivity of the posterior LPP to stimulus valence per se, models of affect and evaluation are increasingly suggesting that the processing of positive and negative information may be distinct. That is, the processing of valence may not fall on a bivariate continuum, but rather two univariate continua (Cacioppo and Bernston, 1994; Tellegen et al., 1999; Watson et al., 1988). In a study using Positron Emission Tomography (PET), Sutton et al. (1997) found that viewing negatively valenced pictures was associated with more activation in right orbitofrontal cortex and right inferior frontal cortex, whereas viewing positively valenced pictures was associated with more activation in the left pre- and post-central gyri. More recently, evidence for right lateralized processing of negative information has been found using fMRI (Anderson et al., 2003; Cunningham et al., 2003, 2004). Specifically, areas of right inferior frontal cortex and anterior insula consistently appear to be involved more in processing negative than positive stimuli. Other studies have found that particular areas of orbitofrontal cortex (Anderson et al., 2003; Kringelbach et al., 2003; Nitschke et al., 2003) and basal ganglia (Delgado et al., 2000; Tanaka et al., 2004) are involved more in the processing of positive affect than negative effect (see Wager et al., 2003 for a meta-analysis). Although such findings do not necessarily imply that the processing of positive and negative stimuli is fully dissociated, they suggest the presence of at least partially separable circuits.

Some of the strongest evidence to date for separate processing of positive and negative information comes from examinations of frontal EEG asymmetries. Specifically, when comparing relative alpha (8–12 Hz) power (recorded with eyes closed), evidence of greater right hemisphere activation is associated with a tendency toward withdrawal behavior (and negative stimuli), whereas evidence of greater left activation is associated with a tendency for approach behavior (and positive stimuli; Sutton and Davidson, 1997, 2000; see Davidson, 2004 for a review). Using this as an individual differences measure, frontal EEG asymmetry has been shown to predict depression (Davidson, 1998), ability to regulate emotion (Jackson et al., 2003), and general well-being (Urry et al., 2004). In addition to being associated with trait differences, asymmetries have been noted following manipulations of positive or negative feedback (Sobotka et al., 1992).

Although the previous research has provided a great deal of information regarding the ways in which the brain processes evaluative information, there is still much that is unknown. For example, although Davidson and colleagues have demonstrated lateralization of frontal alpha power for the processing of positive and negative information, little is known about the time course of this information processing (e.g., as indexed by ERPs). In the current study, we addressed these questions by presenting participants with positive or negative stimuli in an evaluative or nonevaluative context, and recording scalp electrical activity using dense-array EEG. This design allowed us to examine lateralized ERP indices of evaluative processing independently of the evaluative context.

In contrast to other work that has examined frontal asymmetries by comparing alpha band power, a direct examination of ERP components allows for a more detailed mapping of evaluation into information processing stages. Evaluation is not an all-or-none process, and it is likely that many discrete component processes give rise to the phenomenological experience of liking or disliking (Cunningham and Johnson, 2004). Indeed, previous research suggests a model of evaluative processing as an iterative process that recruits progressively more controlled, reflective components. This iterative process begins with subcortically mediated reactions to motivationally significant stimuli and then (optionally) recruits more anterior, lateral regions that are specialized for processing of positive and negative stimuli. Broadly speaking, the earlier processes are more likely to be activated automatically whereas the later processes are more likely to fall under the rubric of controlled processes. In the current study, we examine the time course of evaluative processing with specific attention directed toward differences in the frontal regions. Specifically, we examined the extent to which later processing (i.e., after about 400 ms) of positive and negative stimuli is associated with lateralized anterior ERP components (with greater right hemisphere involvement in processing negative stimuli and greater left hemisphere involvement in processing positive stimuli). Lateralization was considered both in terms of the amplitude of valence-specific components and in terms of the latency of these components. Whereas some models of evaluation suggest that negative stimuli are always processed more quickly than positive stimuli (Cacioppo and Bernston, 1994), we considered the possibility that negative stimuli may be processed more quickly only by regions that are more involved in the processing of negative than positive information. Similarly, positive stimuli may be processed more quickly by regions that are more associated with the processing of positive information. As a result, we examined whether the latency of any valence-specific components would depend on an interaction between the valence of the stimuli and the laterality of the components.

Methods

Participants

Twenty-seven introductory psychology students at the University of Toronto participated in the study for partial course credit. Prior to data analysis, the data from 5 participants were discarded due to technical difficulties during data acquisition, 2 were discarded due to equipment failure (i.e., electrodes impedances were high), and 3 were discarded because of artifacts found in the data after acquisition (i.e., vocalizations). Seventeen participants remained for analysis (4 male, 13 female). Participants ranged in age from 18–21. All participants were native English speakers or had been speaking English fluently for at least 10 years, except for one subject who had been fluent in English for 3 years, and all but one were right-handed.

Materials

Seventy-eight concepts were selected for the study and presented to participants as words. Examples of concepts used in the study were *murder*, *love*, *multiculturalism*, *technology*, *recycling*, *immigration*, *terrorism*, and *babies*.

EEG recording and processing of EEG data

EEG data were collected using a 128-channel Geodesic Sensor Net (Tucker, 1993). Recording and analysis were carried out using the EGI Net Station 3.0 software (EGI, Eugene, OR) on a

Macintosh G4 computer. Impedances were maintained below 50 kΩ at the beginning of the session. All recordings were referenced to Cz, sampled at 1000 Hz, digitized with a 16-bit analog to digital converter, and digitally filtered between 0.001 and 200 Hz. Editing of single trial data was completed offline to reject trials with eye blinks, eye movements, and motor artifacts. Signals exceeding 200 μV and fast transits exceeding 100 μV were discarded from all trials. In addition, all trials containing more than 20% artifacts were eliminated from further analysis. During averaging, all data were re-referenced using the average reference of all 128 sites (Tucker et al., 1994). Data were then filtered using an FIR (Finite Impulse Response) 0.001 to 15 Hz bandpass filter.[1] Stimulus-locked data were segmented into epochs comprised of 150 ms prior to stimulus onset and 2000 ms after onset. Baseline correction of averaged data was carried out using the first 100 ms of each channel.

Procedure

Participants were tested individually in a quiet room. After being fitted with a sensor net, and adjusted to a chin rest, they were seated 45 cm in front of a 17″ computer monitor. Before the task began, overhead lights were turned off. A lamp emitting 100 W of light was placed 205 cm away from the computer monitor and was turned on to allow for visibility. Participants were asked to sit as still as possible throughout the session and not make any noise.

Participants categorized concepts along one of two dimensions (Good/Bad or Abstract/Concrete) and indicated their categorization by pressing one of two buttons on a computer keyboard with their dominant hand. Judgment types were blocked such that participants made 13 judgments of one trial type (e.g., Good/Bad) followed by 13 judgments of the other trial type (e.g., Abstract/Concrete). Participants completed 12 blocks of each type resulting in 156 trials in each condition. Within blocks, stimuli were randomly presented. All stimuli were presented in black letters against a white background. Stimuli were presented at the center of the display in 18 point Courier New font, and subtended an average of 0.76° visual angle. E-prime for PC was used for stimulus presentation and providing markers for EEG data analysis. For each block, an instruction screen indicated whether the block required Good/Bad or Abstract/Concrete responses. Participants pressed a spacebar to clear the instructions and proceed with each block. After a 1000 ms delay, concepts were presented one at a time at a fixed rate: each concept was presented for 2000 ms, followed by a fixation cross for an additional 2000 ms. Participants were asked to make their responses as soon as possible after a target stimulus (i.e., concept) appeared on the screen.

After completing the 12 blocks, EEG recording was stopped, and participants filled out a questionnaire in which all concepts were rated for goodness and badness, as well as emotionality. Participants indicated on a 1 to 5 scale the extent to which the target concept was good and the extent to which it was bad, as well as the extent to which the concepts elicited emotion. Based on the ratings, stimuli were classified as good or bad for the purpose of analysis. Stimuli that were not clearly good or bad were excluded from the present analyses. Data from the first trial within each block were also excluded.

[1] Nearly identical results were obtained using a 70 Hz lowpass with a 60 Hz notch filter.

Results

Behavioral data

Stimuli classified as bad had a mean badness rating of 4.67 and a mean goodness rating of 1.34, and stimuli classified as good had a mean goodness rating of 4.57 and a mean badness rating of 1.20. In addition, ratings of emotional intensity were similar for stimuli classified as bad (M = 2.44) as those classified as good (M = 2.59).

EEG data

Data for EEG analysis were sorted based on participant ratings. After removing trials due to artifacts, 36 trials on average were classified as ones in which participants responded to "bad" stimuli and 34 trials on average were classified as ones in which participants responded to "good" stimuli in the Good/Bad task. For the Abstract/Concrete task, 36 trials on average were classified as ones in which the participants responded to "bad" stimuli and 34 trials on average were classified as ones in which the participants responded to "good" stimuli. Several ERP components were identified during the first 300 ms following stimulus presentation, but none of these varied significantly as a function of valence (although there was a trend for a positive deflection around 200 ms post-stimulus that occurred with greater amplitude for positive stimuli in the left frontal region than in the right, and with greater amplitude for negative stimuli in the right frontal region than in the left, P's < 0.10, one-tailed). Thus, we restrict our discussion to effects associated with later components. In particular, we were interested in a positive-going waveform that began at about 475 ms post-stimulus and was maximal over anterior sites. We identified this waveform as a frontal late positive potential (LPP); the relation between this frontal LPP and the posterior LPP identified by Cacioppo and colleagues remains unclear.

LPP amplitude

For each participant and for each condition, we calculated the mean amplitude of the frontal LPP separately for electrodes covering the right and left anterior scalp regions (see Fig. 1 for electrode locations). The amplitude was calculated as the average amplitude across electrodes for all time points between 400 and 1200 ms following stimulus onset. Mean amplitude rather than peak amplitude was used to capture differences in the extent to which the LPP was sustained over time. The calculated frontal LPP amplitude was subjected to a 2 (laterality) × 2 (valence) × 2 (task) analysis of variance (ANOVA). Cell means are presented in Table 1, and the average waveforms for the right and left frontal regions are plotted in Fig. 2. Consistent with a laterality hypothesis of attitude processing (i.e., right associated with bad and left associated with good), we found a significant Laterality × Valence interaction, $F(1, 16) = 8.78$, $P < 0.01$. Collapsing across task, a larger right-sided frontal LPP was found for stimuli rated as bad (M = 3.34 μV) than good (M = 1.33 μV), and a larger left-sided frontal LPP was found for stimuli rated as good (M = 1.95 μV) than bad (M = 0.18 μV; see Fig. 3). An analysis of the simple effects indicated that this effect was significant for the Good/Bad task ($F(1, 16) = 9.81$, $P < 0.01$) and was a significant trend for the Abstract/Concrete task ($F(1, 16) = 4.07$, $P = 0.06$). Consistent with Davidson (2004), right PFC may be associated with the processing of negative stimuli (typically associated with with-

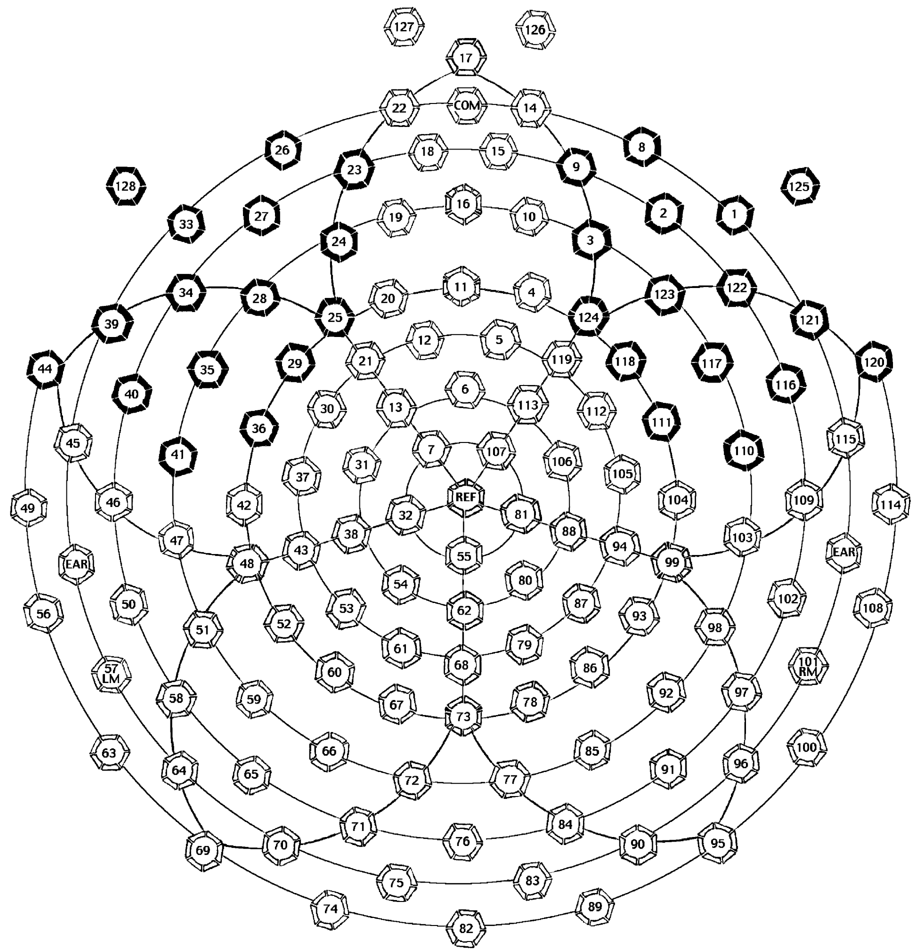

Fig. 1. Electrode locations comprising the right and left anterior scalp regions where the frontal late positive potential (LPP) was recorded.

drawal) and left PFC may be associated with the processing of positive stimuli (typically associated with approach).

In addition, the Valence × Laterality interaction was qualified by a Valence × Laterality × Task interaction, which indicated that the Valence × Laterality interaction was larger for the Good/Bad task (right: mean difference score for bad stimuli minus good stimuli = 2.84 μV; left: M = −2.38 μV) than for the Abstract/Concrete task (right: bad−good M = 1.17 μV; left: bad−good M = −1.16 μV), $F(1, 16) = 4.84$, $P = 0.05$, see Fig. 3. Thus, although the Valence × Laterality interaction was observed in both the Good/Bad and Abstract/Concrete tasks, which suggests that this interaction may reflect some degree of automatic processing, the 3-way interaction involving task indicates that the Valence × Laterality interaction is not immune to reflective processing. For example, although it may be initiated automatically, it is possible that an explicitly evaluative agenda can keep valence-specific information active in working memory (or conversely, that a nonevaluative agenda may suppress such information).

Table 1
Mean amplitudes and standard deviations of the frontal LPP, according to task, valence, and laterality

	Good/Bad task		Abstract/Concrete task	
	Left PFC	Right PFC	Left PFC	Right PFC
Bad stimuli	−0.55 (3.1) μV	3.73 (3.0) μV	0.91 (4.9) μV	2.94 (2.9) μV
Good stimuli	1.82 (2.3) μV	0.89 (3.1) μV	2.07 (3.7) μV	1.77 (3.5) μV

LPP latency

In addition to examining the extent of activation, an advantage of using EEG methods to study evaluative processes is the ability to examine the time course of evaluative processing. For each participant and for each condition, we computed the average onset of the frontal LPP for all electrodes in the right and left anterior scalp regions defined above. The onset was defined as the latency of the peak amplitude of the negative deflection immediately prior to the positive deflection identified as the frontal LPP. The calculated frontal LPP onset was then subjected to a 2 (laterality) × 2 (valence) × 2 (task) ANOVA. Cell means for significant effects are presented in Table 2. A main effect for laterality indicated that on average, the LPP for the right anterior region began earlier (M = 433 ms) than did the LPP on the left (M = 516 ms), $F(1, 16) = 9.64$, $P < 0.01$. Importantly, however, this main effect was qualified by a Valence × Laterality interaction. In contrast to the suggestion that negative stimuli are processed more quickly than positive stimuli for all processes, we found that, for the right frontal electrodes, the onset of the frontal LPP occurred more quickly for negative stimuli (M = 410 ms) than for positive stimuli (M = 455 ms), but that for the left frontal electrodes, the onset of the frontal LPP occurred earlier for

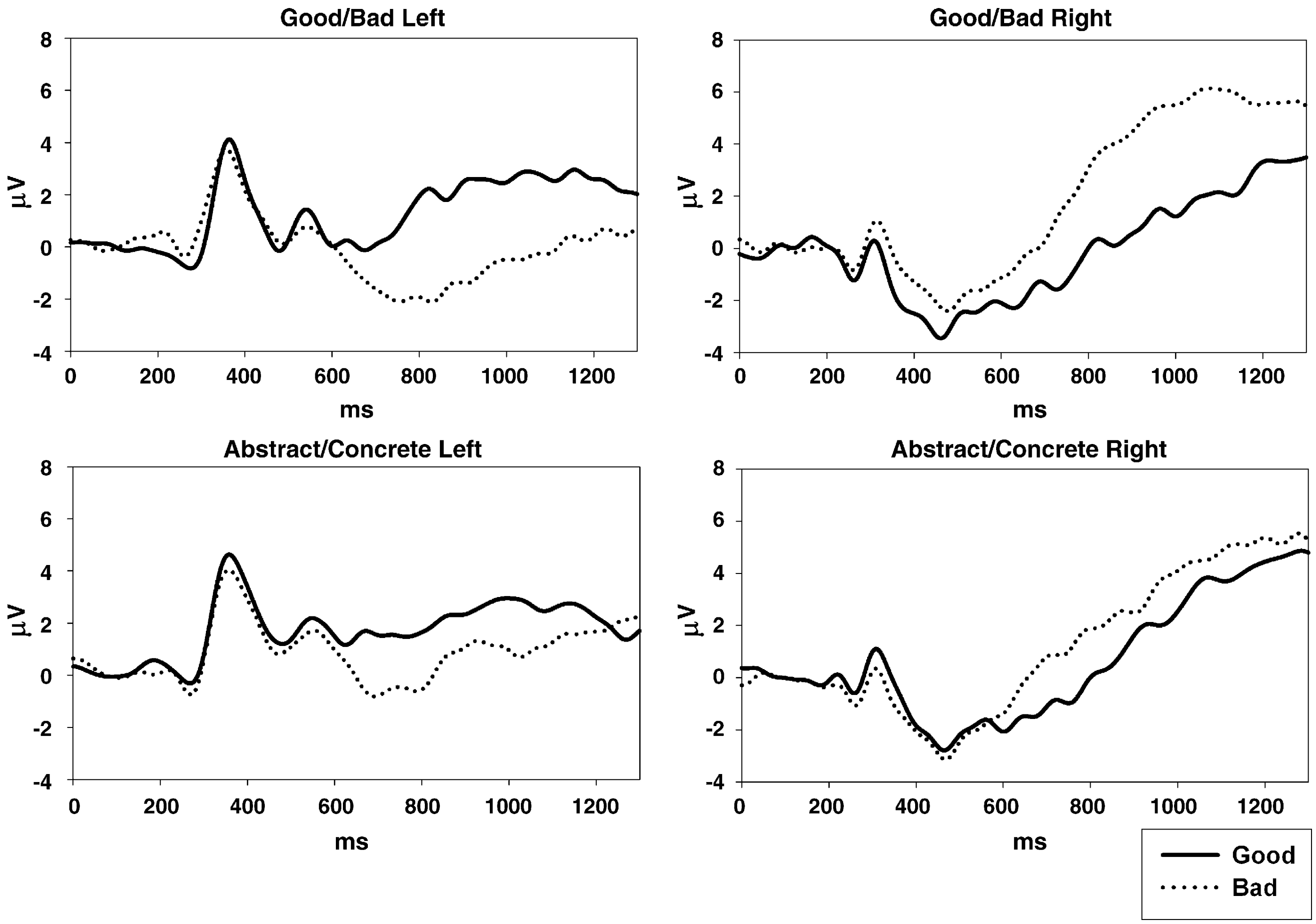

Fig. 2. Average waveforms in the right and left anterior regions for the Good/Bad and Abstract/Concrete tasks. Average waveforms were generated by taking the mean of each participants waveform for each of the electrodes defined in the right and left anterior frontal regions.

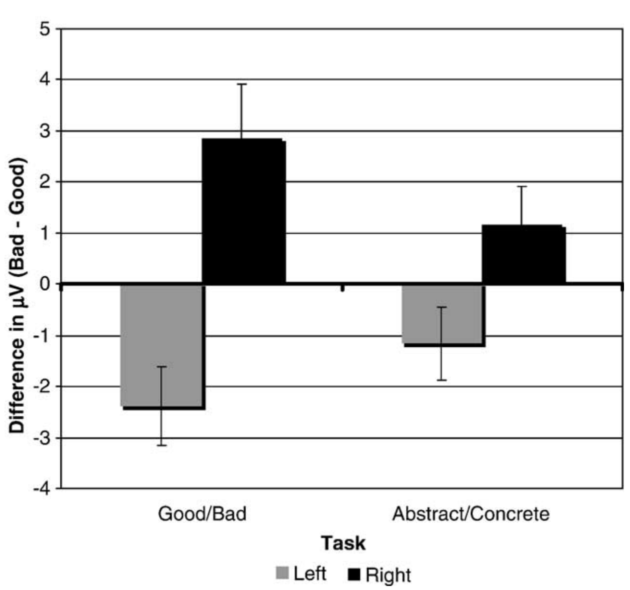

Fig. 3. Difference in mean amplitude (in µV) of the frontal late positive potential (LPP) as a function of task (Abstract/Concrete vs. Good/Bad) and laterality. Positive values reflect a greater LPP to bad compared with good stimuli, and negative values reflect a greater LPP to good relative to bad stimuli.

positive stimuli (M = 490 ms) than for negative stimuli (M = 542 ms; see Fig. 4), $F(1, 16) = 7.80$, $P < 0.05$. An analysis of the simple effects indicated that this effect was significant for both the Good/Bad ($F(1, 16) = 5.15$, $P < 0.05$) and the Abstract/Concrete tasks ($F(1, 16) = 7.22$, $P < 0.05$). Thus, although there was a general tendency for the frontal LPP to occur earlier on the right, consistent with models that emphasize a general negativity bias (e.g., Cacioppo and Berntson, 1994), we found that the latency of the frontal LPP depended on both the valence of the stimuli and the laterality of the component, consistent with the suggestion of lateralized neural systems specialized for the processing of positive and negative information.

General discussion

Despite the relatively long history of the use of physiological methods to study attitudes and evaluation, this history has, for the

Table 2
Mean latency and standard deviations of the frontal LPP, according to task, valence, and laterality

	Left PFC	Right PFC
Bad stimuli	542 (69) ms	410 (62) ms
Good stimuli	490 (74) ms	456 (89) ms

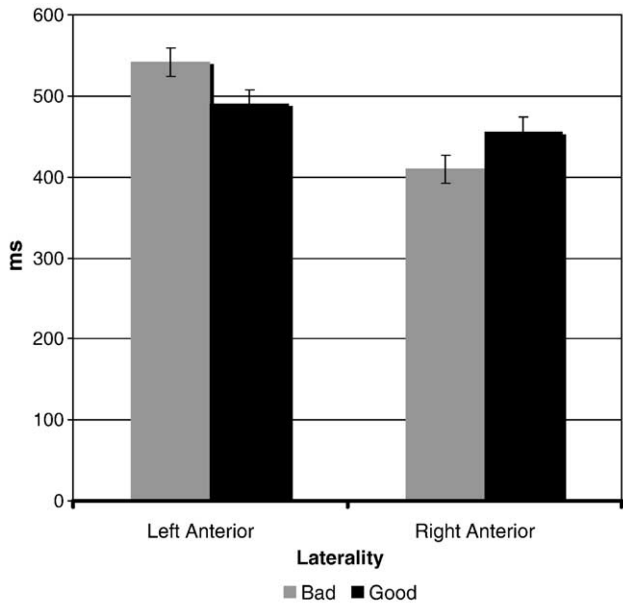

Fig. 4. Mean latency (in ms) of the onset of the frontal late positive potential (LPP) as a function of task, valence, and laterality.

most part, been one of attempting to gain insight into the evaluative states of a person. That is, it was assumed that, by using physiological measures, one could discern someone's *true* attitude. Only more recently have these measures been used instead to examine the mechanisms that give rise to an attitude and to the phenomenological experience of evaluation. In this study, we identified a lateralized frontal LPP that was sensitive to both the valence of the stimulus being processed and the agenda of the processor. Specifically, the LPP over right frontal sites started earlier and had a larger amplitude when elicited by negative stimuli, whereas the LPP over left frontal sites started earlier and had a larger amplitude when elicited by positive stimuli. Although these effects occurred even when participants made judgments that were not explicitly evaluative (i.e., in the Abstract/Concrete condition), the amplitude effects were more pronounced when participants made evaluative judgments (i.e., in the Good/Bad condition).

Previous work by Cacioppo et al. (1996) has identified a posterior LPP that also appears to be involved in evaluative processing. In particular, the posterior LPP is elicited when valenced stimuli are presented in an emotionally incongruous context (e.g., a negative stimulus in the context of positive stimuli). Because the amplitude of the posterior LPP varies as a function of the degree of evaluative incongruity, it has been taken to reflect evaluative processing. It should be noted, however, that the posterior LPP has not been shown to be sensitive to valence. Cacioppo et al. (1996) found that the amplitude of the posterior LPP was greater for negative incongruent stimuli than for positive incongruent stimuli, but the component had the same topography in both cases. Thus, it remains unclear how the posterior LPP is involved in evaluative processing. One possibility is that the posterior LPP is a special case of the P300 in which the incongruity happens to be incongruity of evaluative judgments (Crites et al., 1995). If so, then perhaps the posterior LPP reflects downstream, cognitive processing of outputs of earlier evaluative processing.

In the present study, we found that the processing of valence within a randomized context resulted in hemispheric differentiation for positive and negative stimuli. Consistent with Davidson's work on baseline inverse-alpha power at frontal electrodes (see Davidson, 2004 for a review), we found that the amplitude of the right-sided frontal LPP was greater for self-rated negative compared with positive stimuli. Conversely, the amplitude of the left-sided frontal LPP was greater for positive compared with negative stimuli. Thus, unlike previous ERP work on the processing of evaluation, we found a frontal LPP that is valence-specific.

In addition to finding asymmetries in amplitude effects, we also found systematic latency differences. First, the onset of the right-sided frontal LPP was approximately 100 ms earlier than the onset of the left-sided LPP. This suggests that in general, the negative aspects of stimuli may be processed more quickly than positive aspects of stimuli. From a functional perspective, it is likely more urgent to detect potential threats in the environment (and initiate withdrawal behavior) than it is to detect potential rewards (and initiate approach behavior). This effect may provide a neural basis for greater false alarms to detecting negative than positive stimuli at quick time intervals (Maratos et al., 2000).

A more important finding, from our perspective, is the finding that the onset of the frontal LPP varied as a function of both stimulus valence and laterality. That is, frontal LPP onsets were earlier for stimuli that were matched to the hemispheric specialization of the LPP—onsets were earlier for negative stimuli on the right and for positive stimuli on the left. Thus, discussions of temporal valence bias effects need to take into consideration specific components of evaluative processing. Processes associated with withdrawal motivation may show a negativity bias whereas processes associated with approach motivation may show a positivity bias.

Compared to the posterior LPP, which generally begins around 500 to 600 ms following stimulus presentation, the frontal LPP begins earlier—approximately 475 ms following stimulus presentation. Interestingly, there were no differences in latency as a function of task. At the same time, however, the interaction between stimulus valence and laterality was more pronounced when participants made explicitly evaluative judgments (i.e., in the Good/Bad condition), providing evidence of controlled processing. Thus, although reflective processing appears to occur within the time window of the frontal LPP, the frontal LPP may begin automatically. The frontal LPP therefore fits well with a model of evaluative processing in which motivationally significant stimuli recruit or sustain lateral regions of PFC that are specialized for processing of positive and negative stimuli. To the extent that the processes associated with these regions are controlled, they might be expected to be influenced by variables that affect the likelihood of controlled processing in general, and levels of reflective processing in particular (e.g., Cunningham and Johnson, 2004; Johnson and Reeder, 1997; Zelazo, 2004). For example, as children develop, there are age-related increases in controlled reflective processing (Zelazo et al., 2004) that may be associated with corresponding increases in the amplitude of the frontal LPP. Conversely, asking participants to evaluate concepts while performing another task (i.e., divided attention manipulations) may be expected to diminish the amplitude of the LPP.

It is important to note, however, that this study did not explicitly control for controlled evaluative processes. Rather, one task required an evaluative judgment whereas the other did not. Thus, it is possible that participants may have engaged in controlled evaluative processing of the stimuli even when not required to do so (i.e., in the Abstract/Concrete task), and these effects were simply enhanced by additional reflective processing in the Good/Bad task. It will be important in future research to investigate the possibility that the LPP may be activated automatically and unconsciously—perhaps by using experimental designs in which participants are unable to make consciously evaluative judgments (e.g., when stimuli are presented subliminally).

Another important question to which these data speak concerns whether evaluative space is univariate or bivariate. Are positive and negative responses to stimuli independent, such that one can have positive and negative responses simultaneously (Cacioppo and Bernston, 1994), or are these responses reciprocals on a single dimension and conceptually redundant (Russell, 2003)? Finding asymmetries in both the amplitudes and latencies of anterior waveforms provides strong evidence for the dissociation of the processing of positive and negative information. That is, a single region was not associated with the processing of valence, nor was it the case that in all scalp regions negative stimuli elicited more activity than positive stimuli. Although it is always possible that a single neural generator (or set of neural generators) is responsible for the pattern of data on both the right and the left, the latency data suggest that this is not the case. It is not that the waveforms in the right and left frontal regions were mirrors of one another—the waveform on the right began before the waveform on the left, and the interaction with valence indicated that these waveforms had opposite timing patterns for different stimuli.

Although we have identified a specific ERP waveform—the frontal LPP—that distinguishes between the processing of positive and negative stimuli, it is unclear exactly which information processing computations underlie this waveform, or how this waveform is generated. Future work is required to determine the psychological and neural underpinnings of these asymmetries, although previous research suggests that inferior prefrontal regions are likely candidates. For example, previous neuroimaging research has indicated that that areas of right insula and inferior frontal cortex (Anderson et al., 2003; Cunningham et al., 2003, 2004) appear to be involved in the processing of negatively valenced stimuli whereas areas of left orbital frontal cortex appear to be involved in the processing of positively valenced stimuli (Anderson et al., 2003). Given the particular lateralization of these effects, these regions are likely candidates.

In sum, we have identified ERP asymmetries in frontal EEG that are sensitive to both stimulus valence and processing goals. Greater left LPP activity was observed for positive than for negative stimuli, and greater right LPP activity was observed for negative than for positive stimuli. Although the amplitude of effects was greater in the Good/Bad as compared with the Abstract/Concrete trials, the onset of processing did not vary as a function of task. This finding suggests that the frontal LPP may be initiated automatically, but that reflective processes may maintain or inhibit activity to correspond to a particular goal state. The involvement of both automatic and controlled processes within the lateralized frontal LPP is consistent with a model of evaluative processing as an iterative process that recruits progressively more controlled, reflective components, including components associated with discrete regions of PFC that are specialized for the processing of positive and negative stimuli.

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