

Voluntary facial expression and hemispheric asymmetry over the frontal cortex

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Abstract

Brain activity was monitored while 36 participants produced facial configurations denoting anger, disgust, fear, joy, and sadness. EEG alpha power was analyzed during each facial pose, with facial conditions grouped according to the approach/withdrawal motivational model of emotion. This model suggests that “approach” emotions are associated with relatively greater left frontal brain activity whereas “withdrawal” emotions are associated with relatively greater right frontal brain activity. In the context of a bilateral decrease in activation, facial poses of emotions in the withdrawal condition resulted in relatively less left frontal activation in the lateral-frontal, midfrontal and frontal-temporal-central region, but not in the parietal region, as predicted. Findings in the approach condition were less consistently supportive of predictions of the approach/withdrawal model. Implications for the approach/withdrawal model and for the emotion eliciting potential of voluntary facial movement are discussed.

Descriptors: Hemispheric asymmetry, Emotion, Approach/withdrawal, Voluntary facial movement, Frontal cortex

The present study was designed to address two important issues in emotion research. The first is whether and to what extent emotions that have been identified as basic or modal map onto the motivational states of approach and withdrawal, as indexed by hemispheric asymmetries over the frontal cortex. The second involves the extent to which emotion-related central nervous system activity can be generated as a result of voluntary facial movement.

The Role of Emotional Facial Expressions in Emotion

The role of facial movement in physiological emotional processes and conscious emotional experiences has inspired considerable discussion (e.g., Darwin, 1872/1998; Ekman, 1993; Izard, 1994; James, 1884; Rutledge & Hupka, 1985; Tomkins, 1962). For example, Ekman, Levenson, and Friesen (1983) and subsequently Levenson, Ekman, and Friesen (1990) demonstrated autonomic specificity to emotions using a directed facial action task designed to elicit emotional facial expressions while attempting to keep participants blind to the emotional content of the facial movements. Rutledge and Hupka intensified feelings of anger and joy by first asking participants to make and hold angry and joyful

facial expressions using a directed facial action task similar to that used by Levenson et al.

Emotional facial expression and autonomic nervous system activity. Strategies to investigate emotion-specific ANS activity have included “reliving” emotional experiences in an imaginative procedure (Levenson et al., 1990), showing provocative films (e.g., Gross & Levenson, 1995), showing participants films of facial expressions (e.g., Davidson & Fox, 1982), and asking participants to perform a directed facial action task (Ekman et al., 1983; Levenson, et al., 1990), in which participants are verbally directed through each facial movement, one movement at a time (e.g., “move the inner portion of your eyebrows down and together . . .”) without any visual feedback. Methods involving facial movements may be superior to other forms of induction, as Ekman et al. found that emotions generated with a directed facial action task resulted in finer ANS distinctions between emotions than did a relived emotions task.

Emotional facial expression and central nervous system activity. Researchers investigating central nervous system (CNS) correlates of self-reported emotional experience (Davidson, 1993; Davidson, Ekman, Saron, & Senulis, 1990; Fox and Davidson, 1984), in particular electroencephalographic (EEG) asymmetries over the frontal cortex, have found positive affects such as joy and interest are associated with relatively greater left frontal cortical activation and negative affects such as sadness and disgust are associated with relatively greater right frontal activation. This valence model of anterior cortical asymmetry has increasingly given way to the approach/withdrawal motivational model (Coan & Allen, in press; Davidson, 1993, 1998; Harmon-Jones & Allen,

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1997, 1998; Sutton & Davidson, 1997) of emotion, where emotions that are most often “approach” oriented, such as joy, interest, and even anger (e.g., Harmon-Jones & Allen, 1998; Harmon-Jones & Sigelman, in press) are associated with relatively greater left frontal activation whereas emotions that are most often “withdrawal” oriented are associated with relatively greater right frontal activation (e.g., Davidson, 1993).

The degree to which state-dependent CNS patterns have been observed appears to be at least partially dependent upon the extent to which emotional facial expressions occur. For example, Davidson et al. (1990) were unable to demonstrate frontal cortical asymmetries with an emotion induction procedure involving emotional films until they analyzed solely those moments where their participants displayed clearly visible emotional facial expressions. Similarly, Fox and Davidson (1988) were able to demonstrate frontal EEG asymmetries in infants by attending to moments in infant behavior when facial expressions appeared.

Directed Facial Actions and Hemispheric Asymmetry

Voluntary facial movements may be capable of eliciting specific responses in the CNS. Ekman and Davidson (1993) found that smiles that included activation of the *orbicularis pars lateralis*—a movement referred to as *Duchenne’s Marker* after the French neurologist who first identified its importance—resulted in relatively greater left frontal activation compared to “unfelt” smiles, smiles that did not include this movement. Of great interest in this study was that frontal asymmetries were generated with a truncated directed facial action task, that is, a directed facial action task comparing types of smiles but not other emotional states.

Methodological Considerations

Facial electromyographic (EMG) activity may artifactually contribute to alpha power recorded at scalp sites (Cacioppo, Tassinary, & Fridlund, 1990; Friedman and Thayer, 1991). This problem is potentially compounded by the fact that facial EMG asymmetries—sometimes similar in direction to reported cortical EEG asymmetries—have been observed (Borod, Haywood, & Koff, 1997), although the consistent and robust finding to emerge from this literature is an asymmetry characterized by greater left side activity in facial expressions in general, across all specific emotions and elicitation procedures.

Providing an estimate of the potential magnitude of the EMG contribution to EEG recordings, Friedman and Thayer (1991) conducted a redundancy analysis to account for overlap between cortically derived alpha power and alpha power due to facial muscle activation. Facial EMG accounted for 7% of the variance in cortical EEG activity, whereas cortical EEG activity accounted for only 3% of the variance in facial EMG, suggesting that facial EMG is likely to be responsible for a small but potentially important portion of the variance in scalp-recorded EEG. This study did not, however, specifically address the extent to which asymmetries in facial EMG activity were contributing to asymmetries in scalp EEG.

A second methodological consideration involves the assessment of asymmetry by using a difference score comparing left and right homologous sites. Although such difference scores tend to be highly reliable (Tomarken, Davidson, Wheeler, & Kinney, 1992), and facilitate some analyses (e.g., correlations between asymmetry and other variables), such difference scores will mask any bilateral changes in activity. For this reason, prior to reporting asymmetry scores, it is worthwhile analyzing data at individual sites, treating hemisphere as a factor. Finally, it is worth highlighting that the

present study, consistent with the literature, interprets less alpha power as reflecting greater activation.

The Present Study

With the exception of Ekman and Davidson’s (1993) Duchenne’s smile study, there exist no studies examining whether directed voluntary facial expressions alone can evoke emotion-related hemispheric EEG asymmetries over the frontal cortical regions. The present study investigated whether there would exist emotion-specific frontal EEG asymmetries using the standard set of basic or modal emotions identified by Ekman and others.¹ Drawing from previous work on frontal EEG asymmetry and emotion (e.g., Davidson, 1993; Harmon-Jones & Sigelman, in press), emotion conditions were grouped according to the predictions of the approach/withdrawal model of frontal EEG asymmetry (e.g., Davidson, 1998), leading to the following predictions: (1) approach states will show relatively greater left frontal activation, whereas withdrawal states will show relatively less left frontal activation, and (2) voluntary facial expressions will be sufficient elicitors of frontal EEG asymmetries across motivational conditions.

Method

Participants

Thirty-six introductory psychology students served as participants (10 men, 26 women). All participants were strongly right handed (scoring over 35 on the 39 point scale; Chapman & Chapman, 1987), because previous EEG asymmetry research has always excluded non-right-handed participants (e.g. Tomarken et al., 1992) and emotion may be lateralized differently for right- as compared to left-handed persons (Heller & Levy, 1981). Participants ranged in age from 17 to 24 years, with a mean age of 19.1. The ethnic composition of the sample was 2.7% African American, 2.7% Asian, 18.9% Hispanic, and 75.7% Caucasian.

Procedure

The experimenter informed participants that they were taking part in a methodological study designed to identify artifacts in the EEG signal introduced by muscles on the face and head. Participants were further told that accounting for these muscle movement effects would require them to make a variety of specific movements designed to produce certain types of muscle artifact. It was emphasized that much EEG research has been done in the past without accounting for this muscle artifact, and that it was important to the field that this study be done. Thus, participants were led to believe that they were engaged in purposely generating *error*—muscle artifact. It was hoped that although participants might detect the associations between the directed facial action tasks and their respective target emotions, they would not think of the target emotions per se as being of interest to the investigators. After participants were prepared for psychophysiological recording with

¹It should be noted that the idea of basic emotions is still somewhat controversial in the field of emotion research (e.g., Ortony & Turner, 1990; Turner & Ortony, 1992). It is the opinion of the investigators that the evidence in favor of the existence of emotions that are—at the very least—modal across cultures (hence, “basic”) is thus far more compelling than the evidence contrary to this notion (Ekman, 1992; Izard, 1992; Panksepp, 1992). Therefore, the most common emotions proposed to make up this set were used. It is not an objective of this report to discuss the existence of basic or biologically determined emotions. Rather, basic emotions, particularly the emotions listed here, are assumed to be discrete states, similarly experienced in all humans.

EEG and facial EMG electrodes (see below), participants sat quietly for 8 min during which resting EEG was recorded during a counterbalanced sequence of minute-long eyes-open and eyes-closed segments. For the facial movement task, participants were seated in a sound-attenuated room, separate from the experimenter. The experimenter communicated with participants via microphone, and participants' faces were closely monitored at all times via video monitor. Participant facial expressions were recorded onto videotape, as were subsequent verbal self-reports of experience (see below). The experimenter gave explicit instructions to participants concerning how to make each facial movement, observing participants on the video monitor to ensure that each movement was performed correctly. These instructions² were identical to Levenson et al.'s (1990) study of facial expressions and autonomic physiology, except that they followed a different order of presentation. Participants were asked to perform relatively simple movements first, moving on to more difficult ones. For example, the first movement participants were asked to perform is one that is part of the expression of anger. This movement engages the *corrugator* muscle in the eyebrow and forehead drawing the eyebrows down and together. Subjects were asked to make the movement in the following manner: "move your eyebrows down and together." This was followed by two other *partial* faces, making three partial faces in all. No counterbalancing procedure was used for the control faces, as they were all considered to be a single condition. The order of the subsequent full faces represented a reversal design according to the approach/withdrawal model (approach and withdrawal conditions were performed in an ABAB fashion), but was not otherwise counterbalanced. This reversal design was chosen over a strictly counterbalanced one because the primary conditions of interest were approach and withdrawal, not the separate emotions, per se.

Facial movements were numbered according to Ekman & Friesen's (1978) *Facial Action Coding System* (FACS) and classified into two categories of behavioral tendency—approach and withdrawal. In all, eight facial expressions were performed. In FACS, individual movements are referred to as Action Units (AUs), the term used for the remainder of this report when referring to discrete movements. Approach expressions included joy (AUs 6 + 12 + 25) and anger (AUs 4 + 5 + 7 + 23/24). Withdrawal expressions included fear (AUs 1 + 2 + 4 + 5 + 15 + 20), sadness (AUs 1 + 6 + 15 + 17), and disgust (AUs 9 + 15 + 26 + tongue show). In addition, three partial expressions were used to create a control condition. These movements were used to provide facial expressions that were incomplete. The three controls involved FACS codes 12, 15, and 4, each in isolation. The ultimate order of faces was as follows: AU4, AU12, AU15 (all control), disgust (withdrawal), joy (approach), fear (withdrawal), anger (approach), sadness (withdrawal; see Figure 1). Partial faces were used as controls in this study, rather than the "standard control face," as has been done elsewhere (Ekman et al., 1983; Levenson et al., 1990), because it is unclear how to interpret the standard control face as a control. The standard control face, asking participants to puff out their cheeks slightly and close their eyes, seemed devoid of the other possible factors associated with face making, such as eyes being opened, and the possibility of acting as a target emotion clue. Instead, "partial faces" were included that involved individual facial movements associated with the other target faces; these partial faces were hypothesized to act as ambiguous stimuli.

Participants were instructed, AU-by-AU, to make each target expression. Examples of the directed facial actions are displayed in Figure 1.

The experimenter monitored the adequacy of each movement, providing feedback as needed to allow each participant to achieve the target expression. Participants had no visual feedback, and auditory feedback was only of the nature of describing the intended movement again (e.g., "raise your eyelid"). Participants were asked to hold each expression for a full minute, after which they were given a 30-s break before being asked to hold the same face for another full minute. Thus, participants held each expression for a total of 2 min during which EEG was recorded. This greatly exceeds the recommendation of Davidson et al. (1990) that at least 10 s of artifact-free EEG should be recorded during emotion-related tasks. Immediately following each 2-min facial expression sequence, participants were asked four questions intended to solicit thoughts, emotions, physical sensations (e.g., change in heart or respiration rates) or behavioral urges (referred to here as action tendencies). For example, after completing the directed facial action task of a particular face, each participant was asked each of the following: (1) While making that face, did you experience any thoughts? (2) While making that face, did you experience any emotions? (3) While making that face, did you experience any sensations? (4) While making that face, did you feel like taking any kind of action, like doing anything? If anything was reported, participants were then asked to rate its intensity on a scale of 1 to 7 (1 = *no experience at all*; 7 = *an extremely intense experience*). Finally, participants were asked to rate the difficulty of each facial movement task, following its completion, on the same 1- to 7-point scale.

Assessment of EEG and EMG

To assess anterior asymmetries in EEG activity, tin electrodes in a stretch-lycra cap (Electrocap, Eaton, Ohio) were placed on each participant's head. EEG was recorded at sites FP1, FP2, F3, F4, F7, F8, Fz, FTC1, FTC2, C3, C4, T3, T4, TCP1, TCP2, T5, T6, P3, P4, Pz, O1, O2, Oz, A1, and A2, referenced online to Cz, and rereferenced off-line using different reference schemes, per the recommendations of Reid, Duke, and Allen (1998), who pointed out that these reference schemes do not correlate particularly well. In addition to the online vertex (Cz) reference, a computer-linked mastoids reference and an average reference were derived off-line. The average reference involves subtracting from each site the average activity of all scalp sites, whereas the computer-linked mastoids reference involves subtracting from each site the arithmetic average of the two mastoid leads. The ground lead was on the midline just anterior to Fz. Electrode impedances were reduced to less than 5 K Ω . All sites (EEG and EMG) were amplified by a factor of 20,000 with AC differential amplifiers (bandpass 0.1 and 300 Hz), and digitized continuously at 2048 Hz. To monitor EMG that might contribute to scalp-recorded EEG, pairs of tin electrodes were affixed bilaterally over the frontalis region according to the recommendations of Fridlund and Cacioppo (1986) and to the temporalis region (amplification = 5 K, bandpass = 0.1 to 1000 Hz). To monitor eye movements, an electrode was placed on the nasion and two electrodes were placed at approximately 20% of the nasion-inion distance directly below FP1 and FP2 (left inferior orbit, right inferior orbit, and nasion; amplification = 5 K, bandpass = 0.1 to 300 Hz). The three ocular channels were referenced on-line to Cz, after which an off-line derivation of Nasion referenced to left inferior orbit was constructed to identify ocular artifacts.

²Copies of the script are available upon request from the first author.

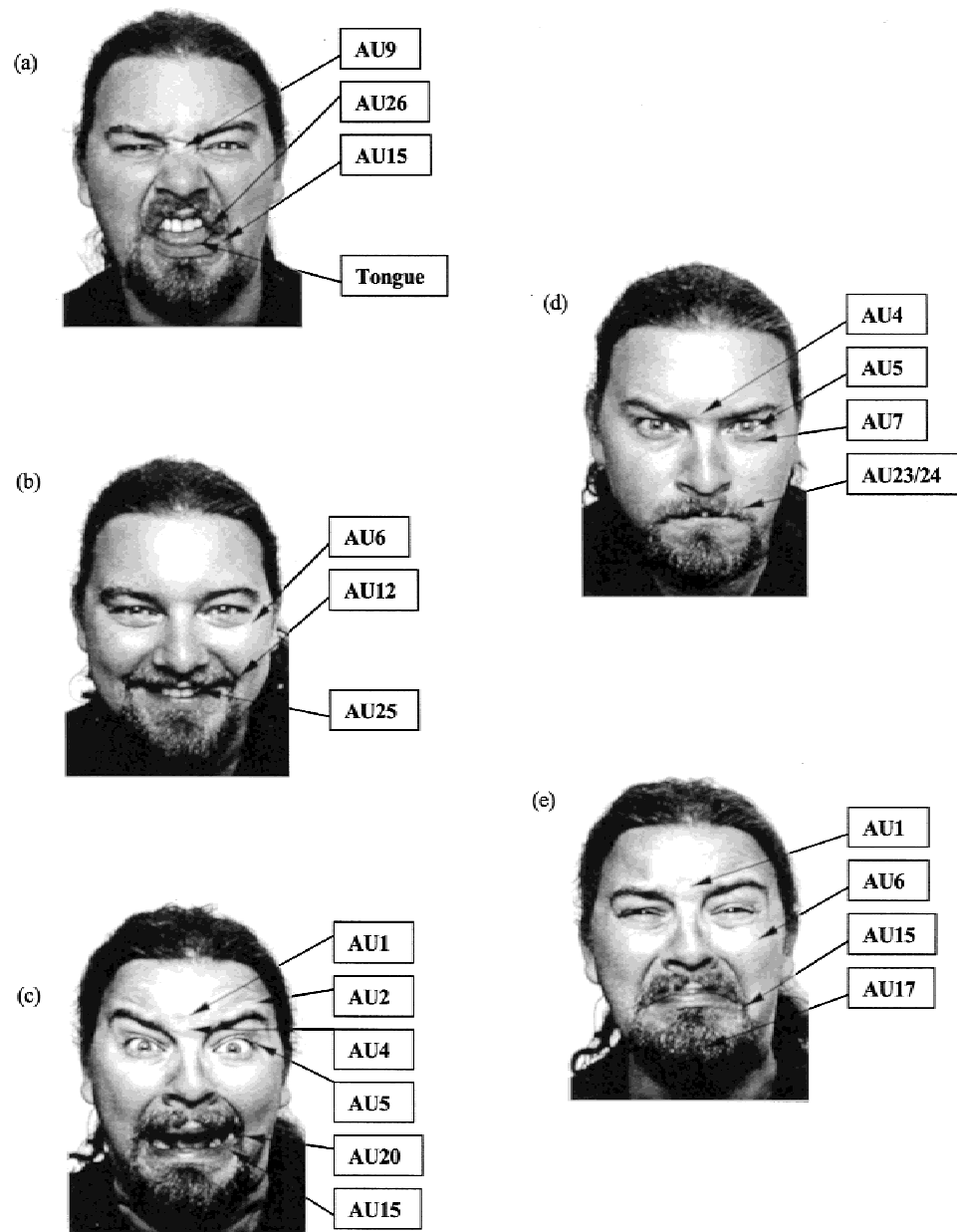


Figure 1. Muscle movements in the full face conditions: (a) disgust, activating AUs 9 (nose wrinkler), 15 (lip corner depressor), 26 (jaw drop), and the “tongue show;” (b) joy, activating AUs 6 (cheek raiser), 12 (lip corner puller), and 25 (lips part); (c) fear, activating AUs 1 (inner brow raiser), 2 (outer brow raiser), 4 (brow lowerer), 5 (upper lid raiser), 15 (lip corner depressor), and 20 (lip stretch); (d) anger, activating AUs 4 (brow lowerer), 5 (upper lid raiser), 7 (lid tightener), 23 (lip tightener), and/or 24 (lip pressor); (e) sadness, activating AUs 1 (inner brow raiser), 6 (cheek raiser), 15 (lip corner depressor), and 17 (chin raiser).

Data Reduction and Analysis

Prior to artifact screening, each data file was filtered with a finite impulse response zero phase shift 161-point digital 60-Hz notch filter. We opted to remove the 60-cycle noise digitally rather than using the analog notch filter, as we could obtain better roll-off characteristics and were interested in indexing EMG activity that may have some of its activity near the 60 Hz range. Removing the 60-cycle noise from the raw data file then made it possible to visually screen each file for epochs with gross movement artifacts and for clipped signals, which were removed from further analyses. Although epochs with excessive muscle artifacts are typically

rejected in EEG research, they were not in this study, because EMG activity was prominent in some facial poses. (Methods for assessing the impact of EMG activity on the results are discussed below.) Eye blinks were manually rejected. Data were then rereferenced off-line to an average montage and to computer-linked mastoids. Data from the online Cz reference and both off-line reference schemes were analyzed separately. Data from each of the 2 min of each facial expression were divided into thirds, and these 20-s epochs were then divided into 40 2-s epochs that overlapped by 1.5 s. The overlap of 75% was selected to compensate for the minimal weighting of the distal portion of each epoch as a result

of the Hamming window. Overlapping ensures that all data are given weight in the final averaged power spectrum. A Fast Fourier Transform (FFT), using a Hamming window that tapered data at the distal 10% of each 2-s epoch, was performed on each epoch, and the average power spectrum across artifact-free epochs for each 20-s period (representing up to 40 epochs) was then obtained. Total power within the alpha frequency band (8–13 Hz) was extracted, and these values were log transformed using the natural log. A measure of EEG hemispheric asymmetry (right hemisphere compared to left hemisphere) was then derived using the formula $[\ln(\text{right}) - \ln(\text{left})]$ for each of the regions of interest (Midfrontal [F3 & F4], Lateral-Frontal [F7 & F8], Frontal-Temporal-Central [FTC1 & FTC2], and Parietal [P3 & P4]). Since cortical alpha power is inversely related to cortical activity (Lindsley & Wicke, 1974), lower scores on this metric indicate relatively less left frontal activation. The use of this particular metric, and of the natural log transformation technique, is relatively standard and follows the recommendation of Davidson et al. (1990), who used it to normalize the distributions, as power values tend to be positively skewed. The frontal regions were included as these sites were hypothesized to show lateralized effects as a function of emotional expression, and the parietal region was included as a control condition where no significant emotion-induced laterality effects were expected.

Results

In all analyses, the sex of the subject was entered as a factor, and in no case did this factor interact with the effects of interest. We therefore report data collapsed across men and women. In analyses of variance with repeated measures involving a factor with more than two levels, violations of the assumption of sphericity are likely. To compensate for this, multivariate analysis of variance (MANOVA) was used in determining main and interaction effects, per the recommendations of Vasey and Thayer (1987). Though MANOVA does assume multivariate normality, it is robust to violations of this assumption. MANOVA does not assume sphericity. Additionally, unless otherwise noted, all planned comparisons were conducted using Student Newman–Kuells tests. Electrode impedances were analyzed initially in a hemisphere (left, right) by region (lateral-frontal, midfrontal, frontal-temporal-central, and parietal) repeated measures MANOVA to determine whether hemispheric imbalances in impedance may have been present during EEG recordings. Results revealed that impedances did not significantly differ as a function of: region, $\Lambda = .85$, $F(3,34) = 1.94$, $p = .14$; hemisphere, $\Lambda = .99$, $F(1,36) = 0.23$, $p = .64$; or a Region \times Hemisphere interaction, $\Lambda = .95$, $F(3,34) = 0.66$, $p = .58$.

Reliability Estimates

Internal consistency reliability estimates (Cronbach's Alpha) were obtained for the alpha asymmetry score for each facial expression by treating the asymmetry score of each 20-s segment as a separate item on a 6-point scale. With this method, 2 min of EEG activity yielded reliability estimates ranging from .39 to .97, depending on the facial expression, scalp region, and reference scheme (see Table 1), with a median reliability coefficient of .83, a mean of 0.81 and a standard deviation of 0.10. Descriptively, the lower reliabilities occurred only with the partial faces, in particular the partial joy face (what Ekman calls the "unfelt smile"). That this occurred with these faces is not entirely surprising, because these faces were particularly chosen for their capacity for ambiguity.

Table 1. Reliability Estimates (Cronbach's Alpha) of EEG Alpha Power Asymmetry ($\ln[\text{right}] - \ln[\text{left}]$) in the 8 to 13 Hz Range Across Emotions, Scalp Regions and Reference Schemes

	Lateral-Frontal	Midfrontal	Frontal-Temporal-Central	Parietal
Anger				
Average	.88	.88	.89	.83
CZ	.86	.87	.91	.87
Lmref	.86	.84	.87	.81
Joy				
Average	.83	.80	.94	.69
CZ	.80	.68	.91	.60
Lmref	.77	.74	.89	.73
Fear				
Average	.97	.90	.88	.81
CZ	.93	.94	.87	.80
Lmref	.94	.91	.86	.75
Sadness				
Average	.88	.91	.85	.74
CZ	.87	.93	.84	.79
Lmref	.81	.90	.77	.74
Disgust				
Average	.75	.75	.81	.82
CZ	.76	.62	.81	.82
Lmref	.76	.68	.76	.80
AU12				
Average	.77	.39	.86	.85
CZ	.80	.76	.88	.88
Lmref	.70	.54	.77	.79
AU15				
Average	.86	.61	.89	.78
CZ	.85	.66	.88	.74
Lmref	.76	.60	.84	.75
AU4				
Average	.85	.62	.86	.76
CZ	.81	.69	.86	.87
Lmref	.85	.69	.86	.70

Note: Calculated from alpha asymmetry scores ($\ln[\text{right}] - \ln[\text{left}]$) drawn from six 20-s segments of EEG recording.

What these lowered reliabilities suggest is that these faces were indeed somewhat ambiguous, even moment to moment and within subjects.

Assessing Hemisphere as a Factor

While the bulk of the results focus on relative differences in activation between hemispheres, it is important initially to place these relative differences within the context of each hemisphere's unique contribution to that relative difference. Thus, the first analysis included hemisphere as a factor, with subsequent analyses utilizing a left/right difference score for the sake of data-analytic economy. Alpha power in each region and for each hemisphere associated with each facial configuration were grouped according to the Approach/Withdrawal model, in addition to the control condition. A condition (approach, withdrawal, control) by region (midfrontal, lateral-frontal, frontal-temporal-central, parietal) by hemisphere (left, right) MANOVA on ln-transformed alpha power at individual sites (F3, F4, F7, F8, FTC1, FTC2, P3, P4) was performed, and a Condition \times Region \times Hemisphere interaction was found in all three reference schemes, all Λ s $\leq .46$, all F s(6,30) ≥ 5.76 , all p s $< .001$. Planned comparisons revealed that alpha power was greater in the left hemisphere during withdrawal con-

dition in all three reference schemes in the frontal regions, $ps < .05$, with the exception of the midfrontal region, which did not differ in the average reference scheme or linked mastoids schemes. Interestingly, alpha power during the withdrawal condition was greater in the right hemisphere in all reference schemes in the parietal region, $ps < .05$. During the approach condition, alpha power was greater in the right hemisphere in the frontal regions using the linked mastoids reference scheme, $ps < .05$, but not using the average or Cz-online references. During the control condition, alpha power was greater in the right hemisphere in the frontal regions using the linked mastoids reference scheme, $ps < .05$, but not using the average or Cz-online references (except the midfrontal region, which also showed greater left alpha using the

average reference). Additionally, a Region \times Condition interaction, noted in all reference schemes, all $As \leq .37$, all $Fs(6,30) \geq 8.49$, all $ps < .001$, revealed a *bilateral* increase in alpha power during the withdrawal condition relative to the approach condition (see Figure 2) in all regions except parietal, $ps < .05$. Alpha power during the withdrawal condition was also higher than that in the control condition in all regions, $ps < .05$, with the exception of the Cz online reference scheme, which showed no difference in the parietal region. To summarize, the withdrawal condition produced a bilateral increase in alpha in frontal regions, but planned comparisons confirmed that, during the withdrawal condition, alpha power was greater in the left than in the right frontal region, $ps < .05$. Because these were within-subjects comparisons, there was no

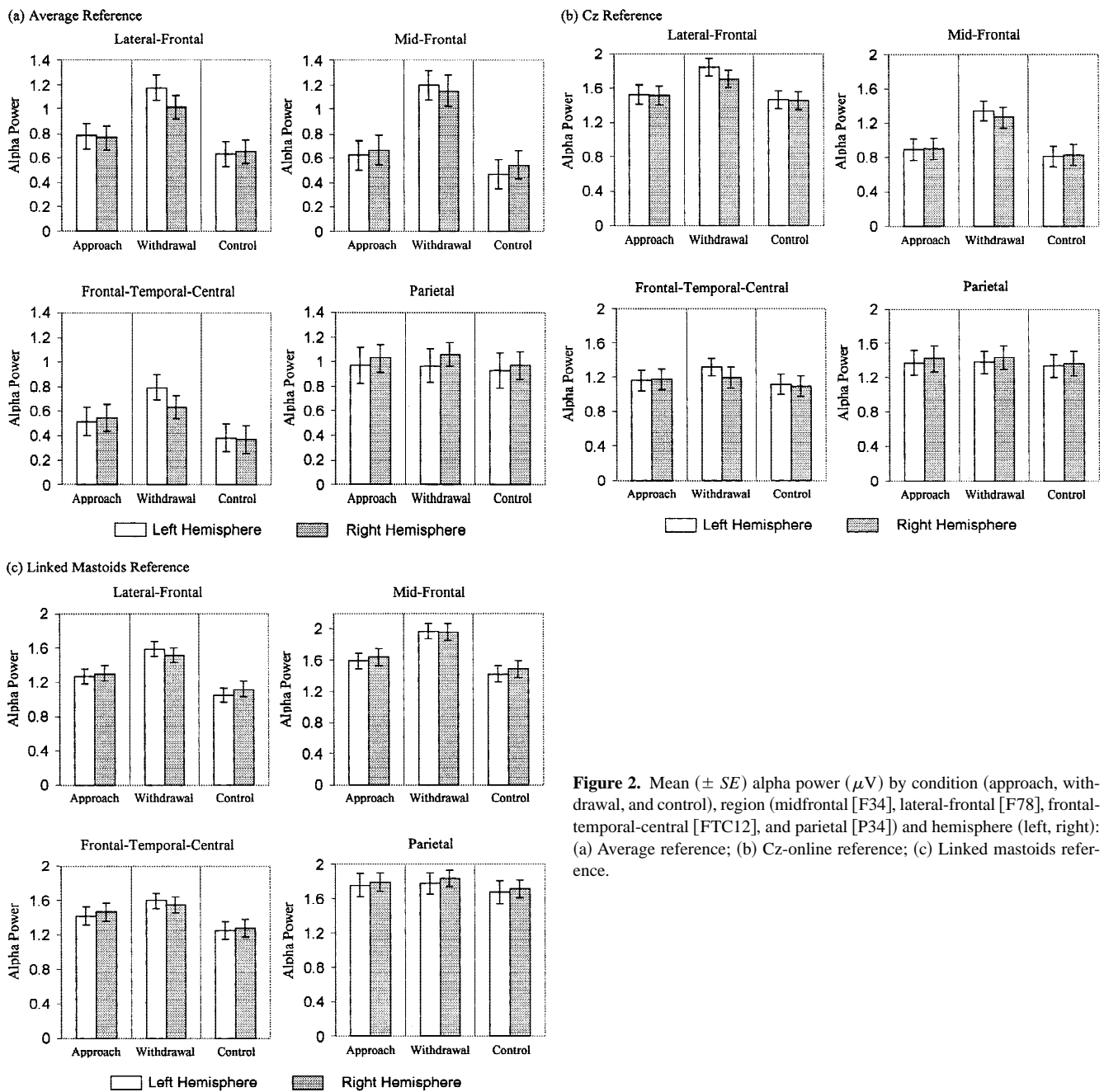


Figure 2. Mean ($\pm SE$) alpha power (μV) by condition (approach, withdrawal, and control), region (midfrontal [F34], lateral-frontal [F78], frontal-temporal-central [FTC12], and parietal [P34]) and hemisphere (left, right): (a) Average reference; (b) Cz-online reference; (c) Linked mastoids reference.

need to correct for individual differences in skull thickness or volume conduction, as might be necessary in research concerned with individual differences or between-subjects comparisons.

EEG Asymmetry as a Function of Approach and Withdrawal Emotions

Alpha asymmetry scores associated with each facial configuration were grouped according to the Approach/Withdrawal model, in addition to the control condition. These three composite asymmetry scores (approach, withdrawal, and control) were then analyzed with a 3 (condition: approach, withdrawal and control) by 4 (region: lateral-frontal, midfrontal, frontal-temporal-central, parietal) repeated measures MANOVA. If facial expressions associated with different motivational tendencies differentially and specifically affected frontal asymmetry, one would expect to see a Condition \times Region interaction. As anticipated, significant Condition \times Region interactions were obtained with all reference schemes (all Wilk's Lambdas (Λ s) $\leq .465$, all corresponding F s [6,30] ≥ 5.76 , all p s $< .001$). Additionally, planned comparisons confirmed relatively less left frontal activation in withdrawal states, compared to approach and control states, in the lateral-frontal, midfrontal and frontal-temporal-central regions, all p s $< .05$, but not in the parietal region. This was true regardless of reference scheme (see Figure 3). The approach and control conditions did not differ significantly from one another in any region or reference scheme. In addition, there was a main effect for the withdrawal condition in all reference schemes, all Λ s $\leq .61$, all F s(2,34) ≥ 7.99 , all p s $< .001$.

Assessing the Contribution of Muscle Artifact

Researchers have noted the existence of facial asymmetries in both voluntary and involuntary facial expressions of emotion (e.g., Borod, 1993; Borod et al., 1997; Matsumoto & Lee, 1993). Because electrical activation in the EMG range may overlap with the alpha range (Cacioppo et al., 1990), others have suggested that alpha power asymmetries, many of which have been observed only during periods of emotional facial activity, may, in part, be the result of facial muscle activity (Davidson, 1998, Friedman & Thayer, 1991). Although the vast majority of EMG power lies above the alpha frequency band (Cacioppo et al., 1990), it is nonetheless important to statistically adjust for EMG asymmetries that were likely to be present. It is important to note that the objective of these and all following covariance analyses was not to statistically control for the effects of the covariates and subsequently interpret the effects of the manipulations on EEG. Miller and Chapman (2001), among others, have argued persuasively that such an approach is not appropriate when conditions differ in terms of the covariate and investigators use the technique in a misguided attempt to determine what the results would be if the conditions did not differ on the covariate. Rather, covariance analyses reported here were conducted to assess whether statistically adjusting the EEG data for several possible covariates eliminated the effects on EEG of interest (cf. Huitema, 1980). In the case of muscle artifact, two analytic strategies were used to accomplish this.

EMG frequencies at scalp sites of interest. In the first analysis, EMG frequencies (70 to 90 Hz) were extracted from the power spectra at each of the sites analyzed above, and asymmetry scores ($\ln[\text{right}] - \ln[\text{left}]$) were computed on this EMG frequency band—for the same regions as the previous analysis. Internal consistency reliability estimates (Cronbach's Alpha) were obtained in the same

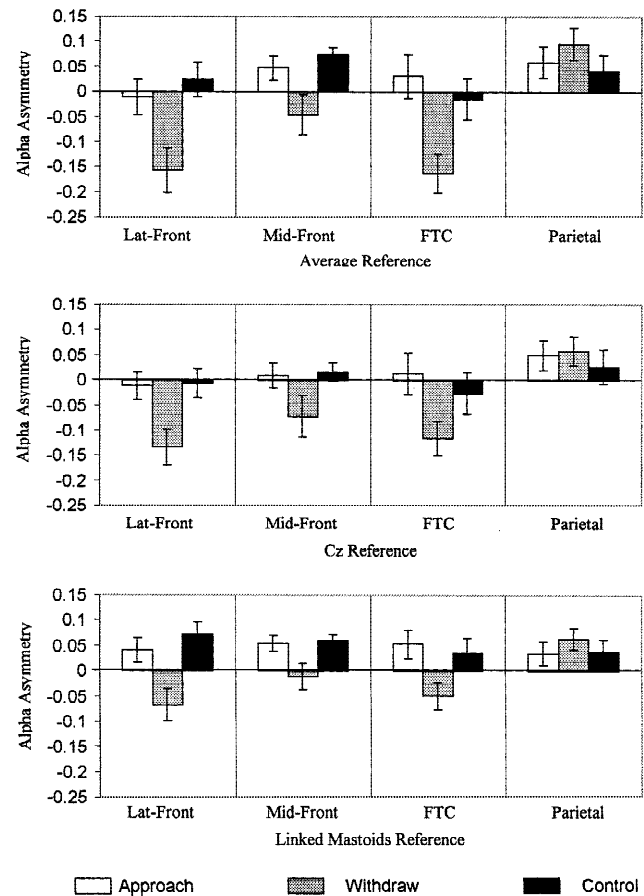


Figure 3. Mean (\pm SE) alpha asymmetry scores ($\ln[\text{right}] - \ln[\text{left}]$) for average, Cz-online, and linked mastoids reference schemes. Data correspond to the Condition (approach, withdrawal, and control) \times Region (midfrontal [F34], lateral-frontal [F78], frontal-temporal-central [FTC12], and parietal [P34]) repeated measures MANOVA. Negative asymmetry scores are indicative of relatively less left hemisphere activity.

fashion as the EEG analysis above, by treating the asymmetry score of each 20-s segment as a separate item on a 6-point scale for each facial configuration. With this method, 2 min of EMG activity yielded reliability estimates ranging from .90 to .99, depending on the facial expression, scalp region, and reference scheme.

These EMG range asymmetries were used as *changing covariates* in a 3 (condition) \times 4 (region) multivariate repeated measures analysis of covariance (MANCOVA). In this and all further covariance analyses, Statistica's MANCOVA module was used with a "changing covariate" specification. This module assumes that the covariate changes within groups with the dependent variable across levels of the independent variable, correlating the change in the covariate with the change in the dependent variable and subsequently analyzing the residual variance in a standard MANOVA. The population parameters in this complex analysis are estimated using ordinary least squares. Results indicated that the interaction effect remained in all reference schemes, all Λ s $\leq .49$, all F s(6, 24) ≥ 3.00 , all p s $< .05$. Further, planned comparisons revealed relatively less left frontal activation in withdrawal states relative to approach and control states in the lateral-frontal, midfrontal and frontal-temporal-central regions, all p s $< .05$, but, again, not in the parietal region.

Alpha frequencies at EMG sites. For the second analysis strategy, alpha power asymmetries were derived from EMG activity in the frontalis region and the temporalis region. Reliability analysis of these alpha-band asymmetry scores derived from the muscle region leads demonstrated internal consistency reliability estimates ranging from .84 to .99 for frontalis and from .89 to .96 for temporalis. Frontalis asymmetry scores ($\ln[\text{right}] - \ln[\text{left}]$) for each motivational condition (approach, withdrawal, control) were included as a *changing covariate* in one-way repeated measures MANCOVAs for each of the EEG regions *separately*, and in each reference scheme. Tests were conducted region by region to overcome analysis limitations introduced by our one measure, for each condition, of frontalis asymmetry (as opposed to the analysis above where we were able to covary EMG frequencies at analogous regions and in each condition). Thus, approach, withdrawal, and control conditions were broken down by region, and frontalis effects were included as changing covariates for each condition (approach, withdrawal, and control) in each region separately. By analyzing each region separately, thus increasing the number of analyses conducted, the chances increased of finding that the covariate rendered a previously significant effect nonsignificant. Missing EMG site data reduced the sample from 36 to 34 for these covariance analyses. Results indicated that the withdrawal condition continued to show less left frontal activation relative to approach and control conditions in all three reference schemes in the lateral-frontal region, all $\Lambda_s \leq .65$, all $F_s(2,30) \geq 7.37$, all $ps < .002$, and the midfrontal region, all $\Lambda_s \leq .76$, all $F_s(2,30) \geq 3.61$, all $ps < .04$. In the frontal-temporal-central region, this effect emerged in the average and linked mastoids reference schemes (but not in the Cz-online reference scheme, all $\Lambda_s \leq .62$, all $F_s[2,30] \geq 5.10$, all $ps < .01$). As before, no significant differences emerged in the parietal region.

Covarying alpha-band asymmetries derived from muscle activity in the temporalis region indicated that the withdrawal condition continued to show less left activation relative to approach and control conditions in all three reference schemes in the lateral-frontal region, all $\Lambda_s \leq .68$, all $F_s(2,30) \geq 6.60$, all $ps < .003$, in the average and linked mastoids reference schemes (but not in the Cz-online reference scheme) in the midfrontal region, all $\Lambda_s \leq .81$, all $F_s(2,30) \geq 3.35$, all $ps < .05$, and the frontal-temporal-central region, all $\Lambda_s \leq .70$, all $F_s(2,30) \geq 3.59$, all $ps < .04$. No effects were found in the parietal region.

Assessing the Contribution of Other Factors to the Observed EEG Effects

Task difficulty. One possible explanation of the asymmetry results was that withdrawal configurations were more difficult to perform than approach configurations. If this were true, it is reasonable to worry that distress experienced by our participants while attempting to perform these configurations resulted in a withdrawal tendency, hence producing or contributing to the results. To test for this, participants were asked to report the difficulty of each facial task on a 7-point scale, where 1 equaled *not at all difficult*, and 7 equaled *extremely difficult*. These difficulty ratings were included as a *changing covariate* in repeated measures MANCOVAs, testing for motivational state (approach, withdrawal, control) differences, for each of the EEG regions, and in each reference scheme. Two participants had to be dropped from this analysis due to missing difficulty report data. Thus, these analyses were performed with an n of 34. As with the tests of frontalis and temporalis muscle activity, these analyses were conducted region by region to overcome analysis limitations introduced by our one

measure of difficulty for each condition (we did not have a measure of difficulty for each condition *and* each region). Results indicated that all withdrawal condition effects remained: in the average and Cz reference schemes, in the lateral-frontal region, all $\Lambda_s \leq .76$, all $F_s(2,30) \geq 3.24$, all $ps < .05$; and in all reference schemes in the midfrontal, all $\Lambda_s \leq .81$, all $F_s(2,30) \geq 3.54$, all $ps < .05$, and the frontal-temporal-central regions, all $\Lambda_s \leq .77$, all $F_s(2,30) \geq 4.47$, all $ps < .05$. It should be noted that the withdrawal effect for the linked mastoids reference scheme in the lateral frontal region was marginally significant, $\Lambda \leq .83$, $F(2,30) = 3.18$, $p = .056$. The parietal region remained nonsignificant.

Task quality. Another important issue is whether and to what extent the effects were due to participants' abilities to produce the target facial configurations. Although all participants were able to complete the facial tasks, overall quality varied. It may have been that the effects were due to those subjects who were particularly adept at voluntary emotional facial expressions. The quality of the target facial configuration was rated by observers during the experiment on a 7-point scale, where 1 meant that no target facial movements were achieved, and a 7 meant that the participant's performance of the target facial configuration was perfect and prototypic. Reliabilities between two independent raters (who observed the video tapes) were calculated on a subsample of 10 participants. Intraclass correlation coefficients ranged from .55 (sadness) to .85 (anger), averaging .68. Overall, mean levels of task quality were quite high (5.36, 4.96, and 5.33 for approach, withdrawal, and control faces, respectively). Task quality ratings were then included as a *changing covariate* in one-way repeated measures MANCOVAs, testing again for motivational state differences, for each of the EEG regions and in each reference scheme. One participant had to be dropped from these analyses due to missing quality rating data. Results indicated that all condition-related asymmetry effects remained, in all reference schemes, in the lateral-frontal region, all $\Lambda_s \leq .67$, all $F_s(2,31) \geq 7.52$, all $ps < .01$, the midfrontal region, all $\Lambda_s \leq .79$, all $F_s(2,31) \geq 4.17$, all $ps < .05$, and the frontal-temporal-central region, all $\Lambda_s \leq .78$, all $F_s(2,31) \geq 4.40$, all $ps < .05$, but again the parietal region condition effects remained primarily nonsignificant. In the average reference scheme in the parietal region, however, the withdrawal condition differed significantly from the control condition, $\Lambda = .81$, $F(2,31) = 3.63$, $p < .05$, revealing relatively greater left activation in the parietal region.

Self-reported emotional experience. It is of theoretical import to address the question of whether the EEG asymmetry effects were dependent upon the self-reported experience of emotion. It may have been, for example, that the effects were achieved to the extent that they were intense enough to be brought into awareness. If so, self-reported emotional experiences following each task should mediate the EEG asymmetry effects. In coding for the subjective experience of emotion, individual differences in reporting were acknowledged by asking for open-ended reports of experience in four different ways. The first asked whether the participant experienced any thoughts during the experimental task. The second inquired about emotions, the third physical sensations (such as changes in heart or respiration rates), and the fourth action tendencies (e.g., "did you feel like taking any kind of action, like doing anything?"). Two independent raters coded each open-ended response for a "hit," a report indicating the target emotion, or a "miss," indicating either no report or a nontarget report. For all participants, Cohen's Kappa was calculated to assess interobserver

agreement in coding hits for each emotion and each question. Kappas were then averaged across reports of thoughts, emotions, sensations, and action tendencies. Kappas for classifying target *thought* hits ranged between .72 and .91, averaging .84. Kappas for classifying target *emotion* hits ranged between .79 and .95, averaging .88. *Sensation* Kappas ranged between .58 and .93, averaging .77, and *action tendency* Kappas ranged between .77 and .88, averaging .83. Once reliability was established, data from the first rater were used to determine the number of hits across response options (thoughts, emotions, sensations, and action tendencies). This number was summed for each motivational condition. These totals were then used to calculate target report percentages. So, for example, if an individual reported a target thought, emotion, sensation, or behavioral tendency, or any combination of the above that was consistent with the target emotion, he or she was scored as having a hit. By this arrangement, the average target experience hit rate was 57.2% ($SD = 11.8\%$; see Table 2).

Reports of physical sensations were dropped from the next, more conservative, analysis due to worries that these reports were too general and might be artificially inflating the overall number of hits for each target emotion by affirming the consequent. For example, whereas a fear experience implies an increase in heart rate, an increase in heart rate alone does not imply a fear experience. To assess the role of subjective experience, a continuous measure of self-reported experience was first created to use as a covariate. This was accomplished in the following manner. First, for the approach condition, hits for reports of thoughts, emotions, and action tendencies for both anger and joy were summed, resulting in a total of between 0 (no reports) and 6 (maximum reports). For the withdrawal condition, hits for reports of thoughts, emotions, and action tendencies were summed for disgust, fear, and sadness, resulting in a total of between 0 and 9, and so forth. Because conditions contained unequal numbers of possible hits, condition sums were divided by the number of possible hits in each condition (e.g., the approach score was divided by 6, the withdrawal score by 9, etc.) to produce a proportion of hits to the number of hits possible for each condition. By this scheme, the proportion of hits to hits possible was 0.40 ($SD = 0.25$), 0.42 ($SD = 0.25$) and 0.45 ($SD = 0.23$) for the approach, withdrawal and control conditions, respectively.

These proportions (one each for approach, withdrawal, and control) were used as *changing covariates* in repeated measures MANCOVAs for each of the EEG regions separately, and in each reference scheme, as in earlier analyses. One participant had to be dropped from these analyses due to missing experience report data. Results indicated that all withdrawal condition effects remained, in

all reference schemes, in the lateral-frontal region, all $A_s \leq .66$, all $F_s(2,31) \geq 7.91$, all $p_s < .01$, the mid-frontal region, all $A_s \leq .79$, all $F_s(2,31) \geq 4.13$, all $p_s < .05$, and the frontal-temporal-central region, all $A_s \leq .76$, all $F_s(2,31) \geq 4.83$, all $p_s < .05$. In the parietal region, the withdrawal condition produced a relative right decrease in activation relative to the control condition in the average reference scheme, $\Lambda = .82$, $F(2,31) = 3.50$, all $p < .05$.

Demand characteristics. Another possible threat to the validity of the results was the extent to which participants might have inferred the purpose of the study and attempted to oblige the experimenter by, perhaps, attempting to feel the target emotions by some unknown method. Unfortunately, the assessment of this possibility was added to the study protocol after the study had been in progress for some time. The result was that approximately 56% of our sample (20 of 36) was asked, after completing the experiment, to describe what they thought the experiment was designed to test. To assess the extent to which participants were indeed able to infer the intent of the study, two independent raters categorized each participant's responses into one of three categories. The first, referred to as the "no idea" group, was for those participants surveyed who either disregarded the question, repeated our cover story, or who reported an experimental intent that was unrelated to any of the aims of the experiment. The second category, referred to as the "vague idea" group, were able to correctly identify that the study was concerned with emotion per se, in some way other than the cover story, or for purely methodological interests, but who were unable to provide specifics about the experimental hypotheses with regard to emotions. The third category, referred to as the "accurate" group, were able to correctly identify that the study was designed to examine the effects of emotional facial expressions on either emotional experience, physiology, or both. High agreement between coders was achieved, with a kappa of .89. Of the 20 participants classified according to this scheme, 13 (65%) were placed in Group 1, 1 (5%) was placed in Group 2, and 6 (30%) were placed in Group 3. The statistical power was too low to include these categories as a categorical variable to test for a possible mixed model interaction. Rather, new analyses were conducted with only those 13 participants who comprised the "no idea" group (thus avoiding any unknown "accurates" who may have been a part of those subjects who were not surveyed). With such a reduction in sample size, the multivariate statistics used in previous analyses were inappropriate. Instead, univariate statistics were conducted with a Huynh-Feldt epsilon correction for violations of the sphericity assumption. The Huynh-Feldt epsilon was preferred to the Greenhouse-Geisser epsilon because it corrects for the Greenhouse-Geisser epsilon's tendency to be conservatively biased, especially with small sample sizes. Additionally, given the dramatic reduction in sample size, Tukey's Least Significant Difference criterion was used for theoretically planned comparisons, as most corrections would, at this level, be too conservative. Results indicated that the condition by region interaction remained significant, with only these 13 participants, in linked mastoids reference scheme, $F(6,72) = 2.57$, adjusted $p = .04$, $\epsilon = .737$. With the average reference scheme, the effect was marginally significant, $F(6,72) = 2.35$, adjusted $p = .056$, $\epsilon = .783$. In both of these reference schemes, planned comparisons confirmed that the withdrawal condition continued to result in relatively less left hemisphere activation in the lateral-frontal, all $p_s < .05$, and frontal-temporal-central, all $p_s < .05$, regions, but not in the midfrontal region. Although the interaction effect did not

Table 2. Rates of Self-Reported Emotional Experience for Each Directed Facial Action Task

	Experience Rate
AU4	63.2%
AU12	63.2%
AU15	63.2%
Anger	65.7%
Disgust	60.0%
Fear	61.8%
Joy	50.0%
Sadness	30.6%

remain with the Cz online reference, simple effects tests revealed relatively less left hemisphere activity during the withdrawal condition in the lateral-frontal region, $F(2,24) = 5.48$, adjusted $p = .01$, $\epsilon = .95$, compared to approach and control conditions. Given the rather drastic reduction in power in these analyses, these results essentially replicate the results with the full sample, and suggest that accurately discerning the intent of the study was not necessary to produce the observed effects.

EEG Asymmetry as a Function of Specific Emotion

In the interest of further exploring the effect of the directed facial action task, frontal EEG asymmetry was examined in each of the eight facial configurations. Because the ordering of the facial actions was a reversal design with respect to the approach-withdrawal model rather than a full counterbalancing designed to test the effect of individual emotions, the following results should be considered exploratory. For these analyses, an 8 (emotion; anger, disgust, fear, joy, sadness, AU4, AU12, and AU15) \times 4 (region; lateral frontal, midfrontal, frontal-temporal-central, and parietal) repeated measures MANOVA was conducted. As expected, a significant Emotion \times Site interaction was obtained with all reference schemes, all $\Lambda_s \leq .22$, all $F_s(21, 15) \geq 2.59$, all $p_s < .05$. Planned comparisons of emotions were assessed by region (see Figure 4). In the lateral-frontal region, fear showed relatively less left frontal activation than anger in the average and linked mastoids reference schemes, relatively less left frontal activation than joy, AU15, and AU12 in all reference schemes, and relatively less left frontal activation than disgust and AU4 in the linked mastoids reference scheme. Sadness showed relatively less left frontal activation than joy in the average and cz-online reference schemes, and relatively less left frontal activation than AUs 15 and 4 in all reference schemes. In the midfrontal region, fear showed relatively less left frontal activation than disgust in the average reference scheme, and relatively less left frontal activation than AUs 15 and 4 in the average and linked mastoids reference schemes. In the frontal-temporal-central region, fear showed relatively less left frontal activation than anger, disgust, AU12, AU15, and AU4 in the average and linked mastoids reference schemes, and relatively less left frontal activation than joy in all three reference schemes. Sadness showed relatively less left frontal activation than joy in all three reference schemes, and relatively less left frontal activation than AU4 in the average reference scheme. (For all planned comparisons reported above, $p < 0.05$.)

Discussion

The primary results are partially supportive of the approach/withdrawal model of frontal activation asymmetry in emotion. These results suggest that facial movements, and facial movements alone, were sufficient to generate the differences in reported experience, and in some cases of EEG asymmetry, between approach, withdrawal, and control conditions. Specifically, voluntary facial expressions of the constituent withdrawal state emotions resulted in relatively less left frontal activation than was apparent in approach or control states, although this occurred in the context of a bilateral decrease in frontal activation for withdrawal states compared to approach and control conditions. Finally, although self-reported emotional experiences did not appear to have produced the asymmetry effects, a high percentage of participants (approximately 60%, averaged across conditions) reported experiencing some facet of the target emotion (thought, emotion, sensation, or behavioral action tendency), suggesting that the directed

facial action task used was also sufficient in eliciting reports of subjective emotional experience.

The Approach/Withdrawal Model

The approach/withdrawal model specifically proposes that approach states should show relatively greater left frontal activation, whereas withdrawal states should show relatively less left frontal activation (e.g., Davidson, 1992). Hemispheric asymmetries over the frontal cortex during these two conditions appear to partially support the predictions of this model—only the withdrawal condition differed significantly from control states. Perhaps withdrawal emotions are more easily evoked than approach using the directed facial action task. Such a speculation is consistent with research suggesting that negative events (which are most often associated with withdrawal emotions) result in greater mobilization of physiological, cognitive, and emotional responses (Ito, Larsen, Smith, & Cacioppo, 1998; Miller, 1959; Taylor, 1991). Similarly, it is possible that the control conditions may have resulted in enough of an approach-oriented state to render statistical distinctions between approach and control states impossible. This possibility is supported in part by the “positivity offset” proposed by Cacioppo and Berntson (1999). According to this process, there is in normal individuals a weak positive or approach-oriented motivational output given minimal or ambiguous stimuli.

Given that both left and right frontal regions revealed decreased activity during the withdrawal states, with a relatively larger decrease in the left frontal region, it is most accurate to characterize these data as reflecting that withdrawal states produce relatively less left frontal activation rather than relatively greater right frontal activation. Despite other research showing increases in right frontal activation during withdrawal states (Davidson et al., 1990), recent neuroimaging data support the finding that changes in left frontal activation may better account for *relative* differences between left and right. Canli, Desmond, Zhao, Glover, and Gabrieli (1998) used functional magnetic resonance imaging (fMRI) to investigate asymmetries in frontal brain reactivity to emotional stimuli. Their pattern of results appears to be similar to many EEG studies concerned with this question, that brain reactivity was relatively stronger in the left hemisphere during positive emotional states and relatively stronger in the right hemisphere during negative emotional states. Although they state that “brain reactivity was lateralized towards the left hemisphere during positive pictures and towards the right hemisphere for negative pictures” (p. 3233), a closer look at their data reveals that across emotion conditions, brain activity in the right hemisphere changed only minimally, whereas brain activity in the left hemisphere changed dramatically—appearing to account for all of the left/right differences reported. These fMRI data, along with data from the present study, suggest that under many conditions that elicit affect in the laboratory, the left hemisphere may be the primary contributor to asymmetry effects. Specific increases in right frontal activity have been seen in other conditions, however, involving an interaction of individual differences and state affect (e.g., phobic anticipating a phobic event; Davidson, Marshall, Tomarken, & Henriques, 2000).

The bilateral increase in alpha presents something of a different puzzle, suggesting that the withdrawal condition resulted in a general decrease in activity over the frontal regions. Perhaps during emotions—particularly emotions that are experienced as quite intense—certain capacities associated with frontal cortical systems are attenuated. Others have theorized about processes that may relate to this possibility. For example, Cosmides and Tooby (2000) have discussed the reallocation of attentional resources

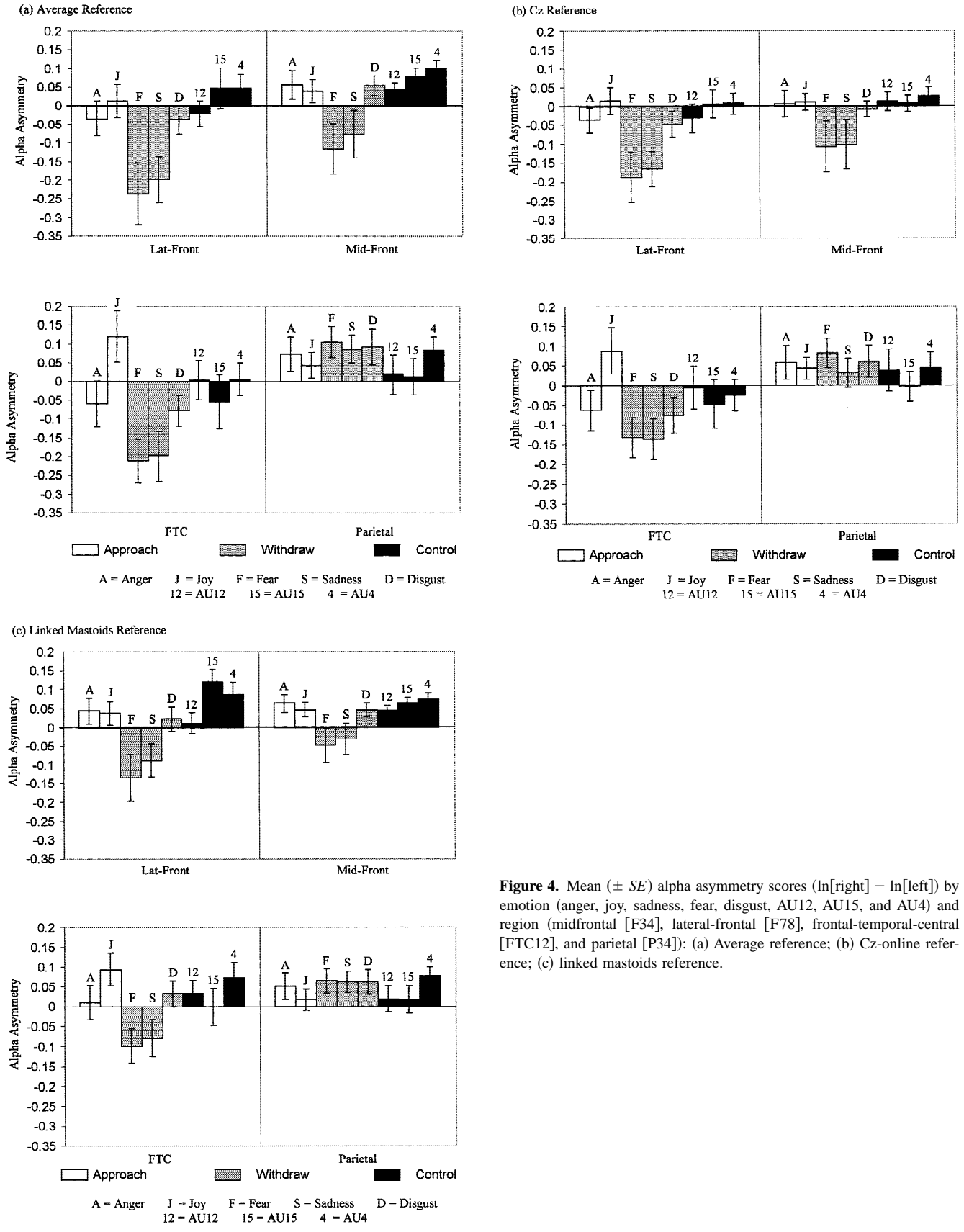


Figure 4. Mean (\pm SE) alpha asymmetry scores ($\ln[\text{right}] - \ln[\text{left}]$) by emotion (anger, joy, sadness, fear, disgust, AU12, AU15, and AU4) and region (midfrontal [F34], lateral-frontal [F78], frontal-temporal-central [FTC12], and parietal [P34]): (a) Average reference; (b) Cz-online reference; (c) linked mastoids reference.

during fear, and Potts, Camp, and Coyne (1989) have noted the attentional impairment that often accompanies sadness.

The Directed Facial Action Task

The directed facial action task appeared to be sufficient to produce the frontal asymmetry effects in this study. This interpretation is bolstered by the fact that numerous alternative explanations were tested by adjusting for them statistically, and in no case were the significant effects of condition on asymmetry eliminated by these statistical adjustments. These covariance analyses included statistically adjusting for patterns of asymmetry in the EMG spectral band at the scalp sites, patterns of asymmetry in the alpha band derived from EMG signals at frontalis and temporalis muscles (hypothesized to be the muscles most likely to result in EMG contamination from the face), and differences across motivational conditions in task difficulty, task quality, and subjective reports of emotional experience. Even a severely truncated sample of 13 individuals who were completely unaware of the goals of the experimental task left the frontal asymmetry effects relatively unscathed.

Assessing the Role of EMG in EEG Asymmetry Scores

Covarying the effects of EMG frequencies at the sites where alpha frequencies were recorded did not alter the pattern of results, nor did covarying asymmetries in alpha band activity resulting from contractions of the frontalis and temporalis muscles. These findings suggest that asymmetries in the EMG band were unlikely to have caused the observed alpha asymmetries. The decrease in the size of the condition effects following the inclusion of alpha power asymmetries derived from frontalis and temporalis EMG activity can be taken as reasonable evidence that the covariate analyses were doing what they were intended to do, which was adjust for the EMG contamination that was likely to be introduced with an experimental task such as the one used. Undoubtedly, some of the cortical effects in the alpha band reported here were due to asymmetries in facial muscle activation, which were superimposed upon veritable cortical asymmetries. This contamination should not come as a surprise, as earlier researchers have noted it (e.g., Davidson, 1988; Friedman and Thayer, 1991), and its potential for data analytical damage is particularly high in a study such as this, where strong facial muscle activation is a part of the experimental design.

Although EMG contamination is a very real concern, and although it does appear to account for some of the variance in cortical emotion-related EEG asymmetry effects, it does not account for all of the asymmetry effects reported here. It is worth noting that although the concern of EMG contributing to EEG asymmetry is especially salient in a study such as this, where strong facial expressions are expected, the concern also extends to other studies of EEG asymmetry and emotion, particularly those where emotion is manipulated (e.g., Hagemann, Nauman, Becker, Maier, & Bartussek, 1998; Wheeler, Davidson, & Tomarken, 1993). The present data suggest that EMG effects need to be assessed in studies of EEG asymmetry, but that they are unlikely to be artifactually creating EEG asymmetry effects where none would otherwise exist. The fact that such functional brain asymmetries exist independently of muscle contributions is supported by the neuroimaging study of Canli et al. (1998), which found left/right frontal activation differences as a function of experimentally elicited emotion. In functional imaging, facial EMG cannot be artifactually localized as brain activation.

Finally, neither the present study nor the functional imaging work mentioned above addresses an additional conundrum regarding the EMG/EEG relationship, articulated by Friedman and Thayer (1991). Friedman and Thayer noted that the possibility yet exists that a third variable, apart from, or in addition to, artifactual sources, may be accounting for the relationship between patterns of facial muscle activation and patterns of frontal cortical activation. That is, in addition to the obvious concern that alpha power of myogenic origin artifactually recorded at EEG leads may be mistakenly inferred to reflect actual EEG activity, there is also the possibility that central nervous system activity causes both EEG and EMG asymmetries (a third variable explanation) or that central EEG asymmetries influence or cause EMG asymmetries (Friedman & Thayer, 1991).

Analysis of Discrete Emotions

Because the study's original predictions were based on the approach/withdrawal model, emotions were grouped according to the model in order to test it. There was, however, a secondary and more exploratory interest in how each emotion behaved individually. Thus, the "omnibus" model, which included in the analysis each of the directed facial task conditions separately, was run. Individually, fear and sadness resulted in relatively less left frontal activation in many instances. In general, anger, joy, and disgust faces did not differ from "partial faces" (AUs 4, 12, and 15). Order effects may have contributed to this result. For example, disgust was always the first full face performed, and anger was always couched between two emotions that showed powerful asymmetry effects (fear and sadness) in the direction opposite to that predicted for anger. A completely counterbalanced design might resolve this problem, although the order in which the faces were performed did represent a reversal design according to the approach/withdrawal model (approach and withdrawal conditions were performed in an ABAB fashion). Alternatively, an increase in the time between conditions would ensure that such emotional responses could return to baseline before the next condition.

Implications

This is the first study to provide evidence that directed facial movements can be a reliable elicitor of withdrawal-related patterns of frontal EEG asymmetry. Further, in addition to contributing to our understanding of asymmetrical frontal cortical activity, this research contributes to our understanding of the effects of facial expression on emotion and motivation. For example, if frontal EEG asymmetry is indeed related to motivational tendencies or to action dispositions, then facial action may itself influence the likelihood of subsequent behavior, with or without subjective awareness. Evidence suggests that the subtle manipulation of facial expressions can influence judgments of other individuals' behaviors in emotion-congruent ways. It is important to note that these effects have been observed even when participants are not aware of a change in their own emotional feelings or the researcher's interest in emotion (Martin, Harlow, & Strack, 1992; Strack, Martin, & Stepper, 1988). The present study suggests a possible neurophysiological mechanism by which such effects may occur. Facial expression is sufficient to alter frontal EEG asymmetry, and frontal EEG asymmetry has been found to predict subsequent responses across a variety of domains (e.g., Harmon-Jones & Sigelman, in press; Wheeler et al., 1993).

Facial action as emotional stimulus. The present study does not resolve or even address the issue of whether cognitions or

physiological/muscular responses are the primary contributors to reports of emotional experience and activity. However, it does lend support to the notion, fostered by many others (e.g., Ekman et al., 1983; Laird, 1974; Levenson et al., 1990; Tomkins, 1962) that voluntary facial expressions alone can act as emotional stimuli. That is, it seems reasonable to interpret these results as supporting the hypothesis that the act of activating one's facial muscles in configurations representing those emotions thought to be of phylogenetic origin is sufficient to generate their respective emotional responses and/or subjective experience reports.

Conclusion

When the present report is considered in the company of the history of research in this area, and the theoretical implications are subsequently distilled, two important conclusions are implied with regard to emotion and motivation: (1) Emotions are probably most fundamentally motivational states, and (2) emotional behaviors—perhaps especially emotional facial expressions—are fundamentally woven into the fabric of emotional and motivational processes and experiences.

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