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# Frontal Brain Asymmetry in Restrained Eaters

Jaime R. Silva
Complutense University

Diego A. Pizzagalli, Christine L. Larson,
Daren C. Jackson, and Richard J. Davidson
University of Wisconsin—Madison

It is well known that the eating patterns that restrain chronic dieters (restrained eaters) can be disinhibited by anxiety, which in turn has been associated with relative right frontal brain activity in independent electroencephalographic (EEG) studies. Combining these two lines of evidence, the authors tested the hypothesis that chronic restrained eating is associated with relative right frontal asymmetry. Resting anterior brain asymmetry and self-reported measures of anxiety and depression were collected in 23 restrained and 32 unrestrained eaters. As hypothesized, groups differed in tonic frontal activity, with restrained eaters showing more relative right frontal activity. Furthermore, relative right frontal activity was associated with greater self-reported restraint. Right-sided prefrontal asymmetry may thus represent a diathesis associated with increased vulnerability toward restrained eating.

By definition, restrained eaters are people who chronically limit their eating behavior in order to prevent weight gain (Herman & Polivy, 1980). Nevertheless, numerous studies have demonstrated that, under certain conditions, these individuals increase their levels of consumption (Heatherton, Herman, & Polivy, 1991; Polivy & Herman, 1985, 1999; Sheppard-Sawyer, McNally, & Fischer, 2000). Such situations include the consumption of a prohibited food, alcohol ingestion, or experiencing strong emotions (Ruderman, 1986).

Of special interest to this investigation is the fact that restrained eaters disinhibit their eating behavior when they experience specific emotional states, particularly anxiety (Sheppard-Sawyer et al., 2000). Researchers have found that the restrained eater's increased consumption is especially pronounced when a source of stress threatens self-esteem (such as failure at a task) in contrast to a physical threat (such as an electrical shock; Heatherton et al., 1991).

It has been proposed that overeating is related to emotion regulation characteristics of restrained eaters. Heatherton and Baumeister (1991) proposed that these individuals escape unpleasant feelings by limiting their attention to the immediate situation without taking into account the long-term implications and significance of their behavior. This escape from negative self-awareness temporarily helps the dieters to "forget" their negative self-image, preventing them from long-term evaluation of their behavior and weakening the inhibition that normally restricts their eating habits. Polivy and Herman (1999) raised a similar point but emphasized the fact that the restrained eater misattributes the anxiety caused by the threat to his/her self-esteem.

## Affective Style and Prefrontal Cerebral Asymmetries

An independent corpus of literature has begun to delineate the neural substrates of affective style: consistent individual differences in valence-specific features of affective responding (Davidson, 1998; Davidson & Irwin, 1999). Circuitry that features the prefrontal cortex as a convergence zone (Damasio, 1989), but also includes other interconnected structures such as the anterior cingulate, amygdala, hippocampus, and insula, has been proposed as the central substrate in generation and regulation of emotional response patterns, which are organized in two large emotional systems: the approach system and the withdrawal system (Davidson, 1998; Sutton & Davidson, 1997). The approach system has been described as a facilitator of appetitive behavior and as generating a particular type of positive affect related to the achievement of goals. The withdrawal system facilitates the retreat of an organism from sources of aversive stimulation and/or organizes the appropriate response when confronted with threatening stimuli (see Davidson & Irwin, 1999, and Davidson, Jackson, & Kalin,

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Jaime R. Silva, Psychobiology Department, Complutense University, Madrid, Spain; Diego A. Pizzagalli, Christine L. Larson, and Daren C. Jackson, Department of Psychology, University of Wisconsin—Madison; Richard J. Davidson, Departments of Psychology and Psychiatry, University of Wisconsin—Madison.

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Correspondence concerning this article should be addressed to Richard J. Davidson, W. M. Keck Laboratory for Functional Brain Imaging and Behavior, University of Wisconsin, 1500 Highland Avenue, Madison, Wisconsin 53705-2280. E-mail: rjdavids@facstaff.wisc.edu

2000, for reviews). In general, it has been found that these two motivational systems are associated with lateralized patterns of activity in the prefrontal cortex. Thus, the right prefrontal cortex is implicated in the withdrawal system, and the left prefrontal cortex is implicated in the approach system (Sutton & Davidson, 1997). A number of investigators have taken differences in the asymmetry of tonic activity in the prefrontal cortex to reflect differences in the relative balance of approach and withdrawal motivation and emotion (Coan & Allen, in press; Davidson & Irwin, 1999).

Several studies have indicated that the level of brain electrical asymmetry that reflects the activity of the prefrontal cortex can be considered a traitlike index (Tomarken, Davidson, Wheeler, & Kinney, 1992). Test–retest stability of measures of brain electrical asymmetry in prefrontal scalp regions have been reported to be of moderate magnitude, in the .50 to .70 range (Tomarken et al., 1992) over a 1-month period. Recent findings in rhesus monkeys (using scalp-recorded brain electrical activity measures that are virtually identical to what are used in humans) have found comparable test–retest stability over a 3-year period (Kalin, Shelton, & Davidson, 2000). In this vein, it has been demonstrated that subjects with a relatively more active left prefrontal cortex or right prefrontal cortex show systematic differences in positive and negative dispositional affect. Individuals with a more tonically activated left prefrontal region tend to experience approach-related positive affect more intensely and are more likely to organize their resources to support behavior related to the achievement of goals. In contrast, individuals with a more tonically active right prefrontal region are predisposed to being more sensitive to threatening stimuli, inhibiting their behavior, and experiencing more intense withdrawal-related negative emotions (Wheeler, Davidson, & Tomarken, 1993). As stressed by Davidson (1992, 1998), frontal asymmetries are best understood as a diathesis. In this view, individual differences in frontal asymmetry do not suffice to cause a specific emotional state but, rather, they predispose the individual to respond under appropriate conditions with approach- or withdrawal-related emotion. Also of potential relevance to understanding the role of prefrontal asymmetries in eating disorders are our recent observations that suggest frontal asymmetry to be related to emotion regulation (Jackson, Burghy, Hanna, Larson, & Davidson, 2000; Larson, Sutton, & Davidson, 1998). These studies indicate that subjects with more right than left frontal activity, compared with their more left-active counterparts, are less able to both automatically and voluntarily regulate their negative affect following an experimental negative emotion elicitation.

## Prefrontal Cerebral Asymmetry as an Explanatory Hypothesis for Restrained Eaters' Emotional Behavior

As mentioned earlier, it has been repeatedly demonstrated that the restrained eater is especially sensitive to anxiety-provoking situations; when exposed to such situations, restrained eaters typically overeat. On the basis of their documented sensitivity to anxiety-provoking situations, we hypothesized that restrained eaters would exhibit greater relative right-sided frontal activity compared with their less restrained counterparts. The objective of this study, therefore, was to explore the hypothesized relation between restrained eating, measured by the Restraint Scale (Herman & Polivy, 1980), and the level of baseline frontal activity asymmetry, measured by the electroencephalogram (EEG). In this way, we could test the prediction that the restrained eaters are characterized by right prefrontal activity. On the basis of stability of brain electrical measures of asymmetric prefrontal activation, we examined the extent to which such indices, collected 1.5 to 2 years in the past, predict current measures of restrained eating. The confirmation of our hypothesis would support the explanatory power of the approach–withdrawal model and open a new line of investigation in the study of chronic dieters.

## Method

### Participants

Participants were 55 female psychology students of normal weight who took part in a broader longitudinal study conducted in the Laboratory for Affective Neuroscience of the University of Wisconsin—Madison. They were subsequently asked to rate their eating patterns according to the Restraint Scale (Herman & Polivy, 1980). Following Polivy and Herman (1999), those participants with a score of 15 or higher on the Restraint Scale were classified as restrained eaters ($n = 23$) and those scoring below 15 were classified as unrestrained eaters ($n = 32$; see Table 1). The Restraint Scale possesses acceptable levels of test–retest reliability as well as construct, criterion, and concurrent validity (Heatherton, Herman, Polivy, King, & McGree, 1988). The mean body mass index (weight/height [$\text{kg/m}^2$]) for restrained eaters was 22.11 (*SD* = 1.82) and was 21.15 (*SD* = 1.73) for unrestrained eaters. All participants were right-handed, as assessed by the Chapman

Table 1
*Means and Standard Deviations of Demographic, Self-Report, and EEG Data*

| | Restrained eaters | | Unrestrained eaters | |
|---|---|---|---|---|
| Measure | *M* | *SD* | *M* | *SD* |
| Age | 18.52 | 0.67 | 18.47 | 0.62 |
| RS score** | 18.43 | 3.38 | 8.75 | 2.64 |
| BMI | 22.11 | 1.82 | 21.15 | 1.73 |
| MASQ-AA | 26.30 | 6.50 | 24.79 | 5.83 |
| MASQ-AD | 14.10 | 2.94 | 12.33 | 2.18 |
| MASQ-GDD | 7.80 | 1.63 | 7.14 | 1.26 |
| MASQ-GDA | 22.39 | 6.51 | 20.75 | 6.22 |
| Log F4 − Log F3* | −0.06 | 0.10 | 0.05 | 0.13 |
| Log P4 − Log P3 | 0.02 | 0.15 | 0.01 | 0.17 |
| Log F3 | 1.15[a] | 0.39 | 1.10 | 0.36 |
| Log F4 | 1.09 | 0.39 | 1.15 | 0.39 |

*Note.* EEG = electroencephalogram; RS = Restraint Scale (Herman & Polivy, 1980); BMI = body mass index ($\text{kg/m}^2$); MASQ = Mood and Anxiety Symptom Questionnaire (Watson, Clark, et al., 1995; Watson, Weber, et al., 1995; AA = Anxious Arousal; AD = Anhedonic Depression; GDD = General Distress—Depression; GDA = General Distress—Anxiety). Restrained eaters ($n = 23$) differ from unrestrained eaters ($n = 32$) on RS scale and frontal asymmetry score.

[a] For restrained eaters, alpha power at *F*3 (1.15 ± 0.39) differed from alpha power at *F*4 (1.09 ± 0.39), $p < .05$.

* $p < .05$; ** $p < .01$).

Handedness Inventory (Chapman & Chapman, 1987). Participants received course credit for an introductory psychology class for their participation and gave their informed, written consent to the study, which was approved by the University Human Subjects Committee.

### *Procedure*

Participants took part in two EEG sessions, separated by 6 weeks (between 39 and 45 days apart). The procedure for each session was identical. After placing the EEG sensors, participants completed eight 1-min resting trials of EEG, four with eyes open, and four with eyes closed, presented in counterbalanced order according to our previously published procedure (Tomarken et al., 1992). Following the EEG recording, the sensors were removed and the participants completed a battery of self-report instruments, including the Mood and Anxiety Symptom Questionnaire (MASQ; Watson, Clark, et al., 1995; Watson, Weber, et al., 1995). We used the MASQ to remove the variance of possible depressive or anxious symptomatology on the EEG data, as this has been repeatedly linked to frontal asymmetries (Davidson et al., 2000). In addition, our main interest was to study the relation between restraint eating and the levels of asymmetry independently of affective symptomatology at the time of the EEG evaluation.

Between 1.5 and 2 years after the EEG recording, participants completed the Restraint Scale. Because this scale allows identification of chronic as opposed to sporadic dieters (Heatherton et al., 1988), the fact that the participants' eating status was not assessed at the EEG session is of less concern given the chronic nature of restrained eating.

Administration of the Restraint Scale was conducted entirely double-blind with respect to participants' frontal asymmetry.

### *EEG Recording and Analyses*

EEG measures were recorded using the 128-channel Geodesic Sensor Net (Electrical Geodesics, Inc., Eugene, OR). The EEG sensors were referenced to the vertex. Offline, the data were re-derived to the average reference. Sensor impedances were kept below 45 k$\Omega$. EEG data were collected using a sampling rate of 250 Hz and bandpass filtered at 0.1–100 Hz. The EEG was visually scored and edited to remove artifact due to eye blinks, gross muscle activity, and movement. Artifact-free epochs of data were extracted through a Hanning window. A Fast Fourier Transform was applied to all extracted data that were 1.024 s in duration, with epochs overlapping 50%. The mean number of seconds of artifact-free data across trials and assessments was 460.40 ($SD = 31.10$) and did not differ between groups. Power density ($\mu V^2$/Hz) was then computed for the alpha band (8–13 Hz) by summing power values across each 1-Hz bin within a band and dividing by the number of bins. Trials with less than 10 s of artifact-free EEG were dropped from computations. Mean alpha power was computed separately for eyes-open and eyes-closed trials, weighted by the number of available artifact-free epochs. Subsequently, a simple mean of alpha power for eyes open and closed was computed (Tomarken et al., 1992). Finally, average alpha power across both assessments was computed. All power density values were log transformed to normalize the distribution of the data.

Prior research has indicated that the midfrontal sites F3 and F4 are reliably related to dimensions of approach- and withdrawal-related emotion (Sutton & Davidson, 1997; Wheeler et al., 1993), whereas the parietal sites P3 and P4 do not covary with these dimensions and can thus be used as control sites to test the specificity of frontal results. On the basis of this research, we selected these four sites a priori to test our hypotheses regarding relations between EEG asymmetry and restrained eating. To take advantage of our high-density recording and to improve reliability, we created aggregate sites by averaging the standard F3, F4, P3, and P4 sites of the 10/20 system with their nearest six neighboring sensors. In subsequent sections of this article, our use of these site labels refers to the spatial composites and not to values derived from single sensors. Asymmetry scores were calculated for the aggregate frontal and parietal sites by subtracting the log-transformed power density value in the alpha band for the left site from that of the right site (e.g., log F4 − log F3). Positive asymmetry scores thus reflect greater left-sided activity (i.e., greater alpha band power density on the right than on the left).

## Results

A 2 × 2 mixed-model analysis of variance (ANOVA), with group (restrained vs. unrestrained) as the between-groups variable and region (anterior vs. posterior) as the repeated measures variable, was performed on the asymmetry scores (log F4 − log F3; log P4 − log P3). The analysis showed a main effect of group, $F(1, 53) = 4.19$, $p < .05$, which was qualified by a Group × Region interaction, $F(1, 53) = 4.04$, $p < .05$. As evident in Figure 1A and Table 1, the groups differed in their asymmetry scores at frontal sites only (post hoc $t$ tests: F4 − F3: $p < .002$; P4 − P3: $p > .87$). No significant differences were found between the groups in the MASQ scores (all $p$s $> .30$).

In a complementary analysis, Pearson correlations were computed between the asymmetry scores at frontal and posterior sites and scores on the Restraint Scale. For frontal ($r = -.43$, $p < .01$; see Figure 2) but not posterior ($r = .04$, $p > .68$) sites, a reliable correlation emerged with Restraint Scale scores. The correlation with frontal asymmetry scores was significantly different than the correlation with parietal asymmetry scores, $t(52) = -2.42$, $p < .02$ (Steiger, 1980). These correlations remained even after removing the variance accounted by the MASQ Anxiety and Depression scores (F4 − F3: $r = -.42$, $p < .01$; P4 − P3: $r = .06$, $p > .68$). Thus, lower restraint scores were related to relative left frontal activity, and higher restraint scores with relative right frontal activity. Correlations between MASQ scores and asymmetry scores at both regions were all nonsignificant (all $r$s between $-.07$ and $-.19$, all $p$s $> .17$). For descriptive purposes only, a topographic map of Pearson correlations between scalp alpha power asymmetry scores and scores on the Restraint Scale was computed. As evident from Figure 2B, the effects were specific to midfrontal sites.

To test whether group differences were mainly due to differential activity over left or right frontal regions, an analysis of variance (ANOVA) on alpha power values with group and hemisphere (F3 vs. F4) as factors was performed. The only reliable effect emerging was a Group × Hemisphere interaction, $F(1, 53) = 6.36$, $p < .015$ (Figure 1B) in the expected direction: Whereas restrained eaters showed a significant pattern of right greater than left activity, $t(22) = 2.62$, $p < .02$, unrestrained eaters had a reverse, albeit nonsignificant, pattern, $t(31) = -1.43$, $p = .16$. No group differences emerged in either hemisphere ($p > .50$).

On an individual level, 18 of the 23 restrained eaters (78.3%) showed a pattern of left greater than right alpha power, binomial $P(18/23) < .01$, whereas only 10 of the 32 unrestrained eaters

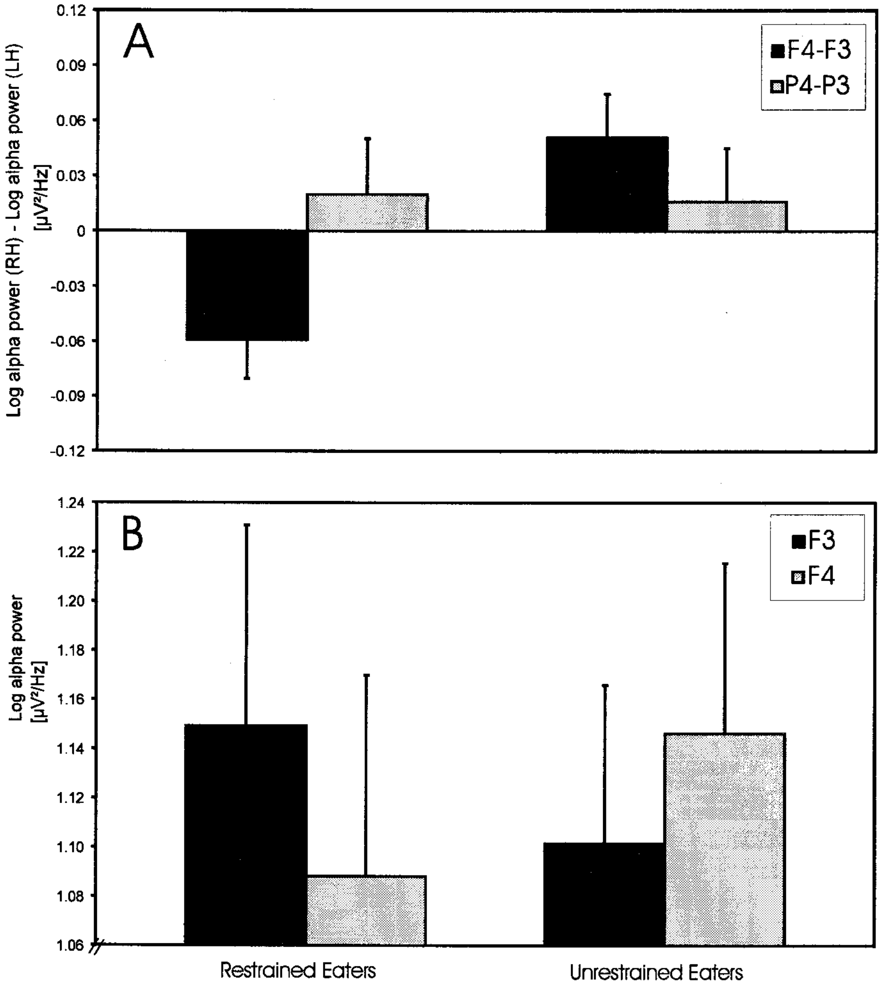

*Figure 1.* (A) Asymmetry scores at frontal (log F4 − log F3) and parietal (log P4 − log P3) sites for restrained ($n = 23$) and unrestrained ($n = 32$) eaters. Means and standard errors are shown. Negative scores reflect relative right frontal activity. RH = right hemisphere; LH = left hemisphere. (B) Alpha power (log-transformed) at the left (F3) and right (F4) frontal sites for restrained and unrestrained eaters. Note that alpha power is inversely associated with activity.

(31.3%) showed such a pattern, binomial $P(10/32) < .03$; 78.26 vs. 31.25, $\chi^2(1, N = 55) = 11.83$, $p < .005$.[1]

## Discussion

Our results confirm the general hypothesis that, in a population of unselected female university students, restrained eaters are distinguishable from unrestrained eaters in frontal activity asymmetry, with the former showing greater right-sided frontal activity compared with the latter. It is important to note that such effects were not produced by variations in self-reported levels of anxiety or depression (MASQ) assessed at the time of the EEG recording; the effects remained after statistically removing the variance in frontal asymmetry associated with the MASQ scales. In addition, the fact that these findings emerged despite the long period of time between the EEG recording sessions and eating behavior assessments suggests that the pattern of frontal activity may be a traitlike characteristic of restrained eating. These findings are consistent with numerous studies demonstrating differences in the emotional behavior of restrained and unrestrained eaters in response to challenging situations and further suggest a biological substrate for these behavioral differences. However, due to the correlational nature of this study, the alternative hypothesis that frontal asymmetry is the result of chronic restraint eating cannot be ruled out.

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[1] The binomial statistics assumed a 50% chance of left greater than right frontal activity. In the larger sample of 189 participants from which the present sample was selected, 52.9% of the participants showed an asymmetry score in favor of the left hemisphere (i.e., right greater than left alpha power). When we repeated the binomial statistics using this adjusted base rate, the results were confirmed; $P(18/23) < .003$, and $P(10/32) < .05$.

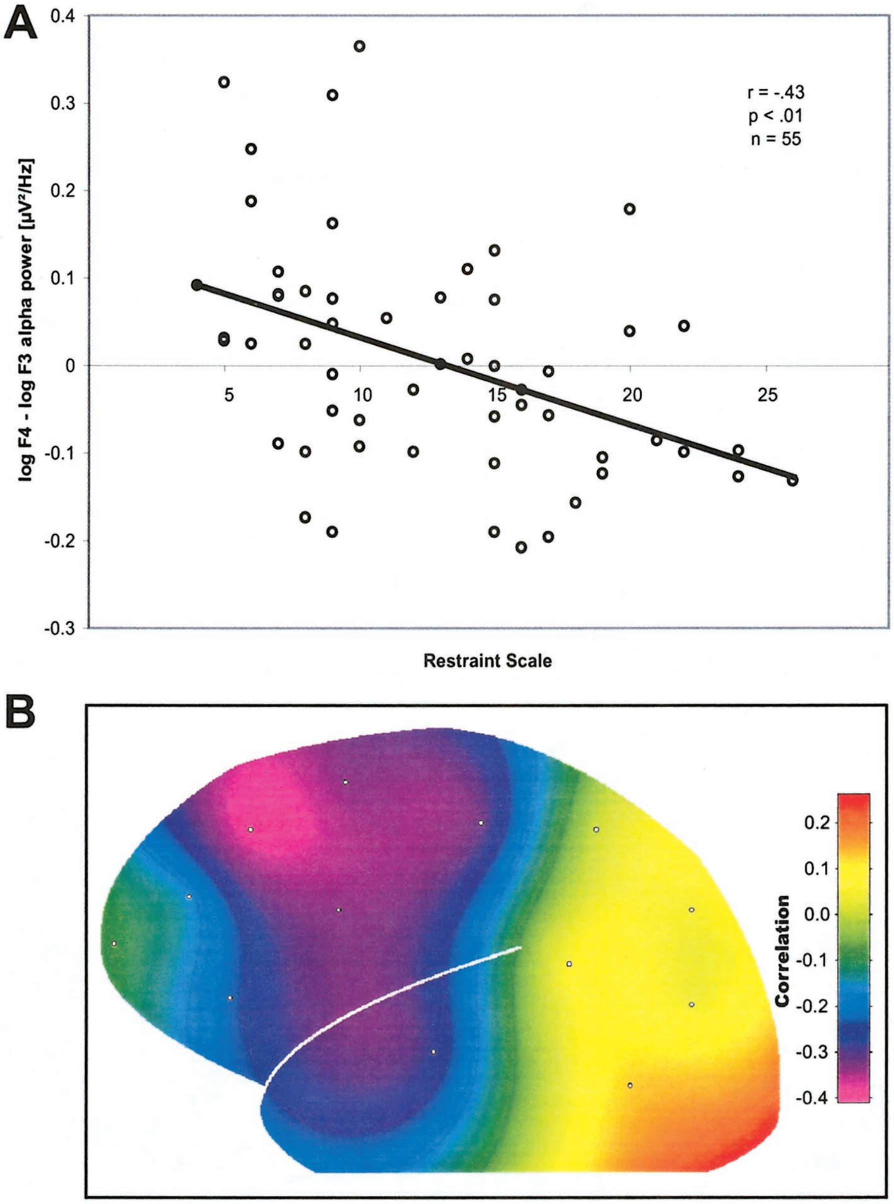

*Figure 2.* (A) Scatter plot and Pearson correlations between the Restraint Scale and Asymmetry scores for the frontal sites (log F4 − log F3). (B) Topographic map of Pearson correlations between scalp alpha power asymmetry scores (e.g., log F4 − log F3) and scores on the Restraint Scale. The map was created by calculating the correlation for standard electrode position of the 10/10 system (small circles). These correlations were then used to generate a spline-interpolated map across a lateral view of the head for display purposes only. Negative correlations (blue tones) reflect increasing scores on the Restraint Scale with decreasing alpha asymmetry scores, that is, relatively lower alpha power (more activity) at right-sided sensors.

Using the approach–withdrawal model as a theoretical framework, we can conceptualize restrained eaters as subjects whose withdrawal system is predominant, which in turn explains their predisposition to respond with negative affect to certain stimuli and the subsequent difficulty these individuals typically have in regulating these emotions once activated.

Certainly, this conceptualization requires some qualifications. First, the prefrontal asymmetry index should not be understood as the sole indicator of the difference between restrained and unrestrained eaters. Given the importance of subcortical structures such as the amygdala in emotion (Davidson & Irwin, 1999), it is likely that the circuitry that subserves emotion regulation and affective differences between restrained and unrestrained eaters will include both cortical and subcortical territories, particularly those with reciprocal projections with the prefrontal cortex. Second, the results demonstrate that not all restrained eaters possess tonic right prefrontal activity, and some unrestrained eaters have right-sided activity. Thus, right-sided prefrontal asymmetry is neither necessary nor sufficient for producing a restrained eater. Individual differences in prefrontal asymmetry should thus be best conceptualized as a contributory factor of these differences in eating style. Finally, increased right frontal activation is not likely to be a specific correlate of restrained eating, but it does appear to characterize various forms of anxiety and negative affect (Davidson & Irwin, 1999).

Behavioral studies also underscore the heterogeneity within restrained eaters. For example, Polivy, Heatherton, and Herman (1988) reported the existence of a group of restrained eaters who do not disinhibit their eating behavior when faced with stressors. In that study, Polivy et al. (1988) found that the best predictor of disinhibition was the subject's level of self-esteem. It would be interesting to conduct a study that distinguishes the restrained eaters who disinhibit their eating behavior from those who do not in order to compare their patterns of prefrontal asymmetry. We would hypothesize that the subjects who respond by disinhibiting their behavior would be predominantly those restrained eaters with more tonic right prefrontal activity.

Two limitations of the present study should be mentioned. First, these results may not generalize to other samples, as only female undergraduate students were tested. Second, the correlational nature of this study does not allow testing the causal relations between frontal asymmetry and eating behavior. Nevertheless, our study represents an initial examination of one hypothesized biological correlate of restrained eating. In light of the nomological network of associations that have been amassed on the correlates of tonic right prefrontal activity, it would now be of great interest to examine the interaction of stress and eating on patterns of prefrontal activity to determine more specifically how individual differences in prefrontal activity influence reactivity to food and other appetitive stimuli in both the presence and absence of other stressors. Our data imply that extreme right-sided prefrontal asymmetry may represent a diathesis that increases an individual's vulnerability to a pattern of restrained eating and possibly also to other eating disorders such as bulimia, for example. This conjecture should be examined in future longitudinal research.

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