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Depression, Anxiety, and Resting Frontal EEG Asymmetry: A Meta-Analytic Review

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Emotion-related disturbances, such as depression and anxiety, have been linked to relative right-sided resting frontal electroencephalograph (EEG) asymmetry among adults and infants of afflicted mothers. However, a somewhat inconsistent pattern of findings has emerged. A meta-analysis was undertaken to (a) evaluate the magnitude of effects across EEG studies of resting frontal asymmetry and depression, anxiety, and comorbid depression and anxiety and (b) determine whether certain moderator variables could help reconcile inconsistent findings. Moderate effects of similar magnitude were obtained for the depression and anxiety studies, whereas a smaller effect emerged for comorbid studies. Three moderating variables predicted effect sizes: (a) Shorter EEG recording periods were associated with larger effects among adults, (b) different operationalizations of depression yielded effects of marginally different magnitudes, and (c) younger infant samples showed larger effects than older ones. The current data support a link between resting frontal EEG asymmetry and depression and anxiety and provide a partial account of inconsistent findings across studies.

Keywords: depression, anxiety, meta-analysis, frontal asymmetry, electroencephalography

In the last 25 years, there has been an explosion of research concerning hemispheric brain asymmetries as they relate to certain dimensions of emotion, personality, and psychopathology. In particular, a substantial number of electroencephalographic (EEG) studies have found a link between hemispheric asymmetry in frontal regions of the cortex and depressive symptoms. These studies typically but not always find reduced left frontal and/or increased right frontal activity at rest in depression. These data have been interpreted in the context of theory proposing hemispheric specialization for cortical systems mediating motivational and emotional processes. In these models (Davidson, 1992, 1998a; Kinsbourne, 1988; Silberman & Weingartner, 1986), left frontal areas mediate approach motivation and/or positive affect, whereas right frontal areas mediate withdrawal motivation and/or negative affect. A diathesis-stress framework has been proposed (see Coan & Allen, 2004) in which the atypical pattern of resting frontal cortical asymmetry serves as a stable, traitlike risk factor for the subsequent development of depression or other emotion-related disturbances.

Resting Frontal EEG Asymmetry and Psychometrically Defined Depression

In one early study (Schaffer, Davidson, & Saron, 1983), high and low scorers on the Beck Depression Inventory (Beck, Ward, Mendelson, Mock, & Erbaugh, 1961) were compared with respect to EEG asymmetry at frontal and parietal recording electrodes while at rest. The investigators computed an asymmetry difference score by subtracting overall activity in the alpha frequency band at the left electrode from alpha activity at the right electrode. Given that alpha is inversely related to cortical activity (Cook, O'Hara, Uijtdehaage, Mandelkern, & Leuchter, 1998; Oakes et al., 2004; see also Allen, Coan, & Nazarian, 2004), positive scores represented greater left than right cortical activity, and negative scores represented greater right than left cortical activity. Participants who were high in self-reported depressed mood exhibited significantly lower asymmetry difference scores, indicative of greater relative right-sided frontal cortical activity, than participants who were low in self-reported depressed mood. No significant findings were obtained for the parietal sites. Some subsequent studies, in which group membership was similarly determined on the basis of self-reports of depressive symptoms, have failed to replicate these findings (e.g., Nitschke, Heller, Palmieri, & Miller, 1999; Reid, Duke, & Allen, 1998). A related strategy involves correlating a depression scale's full range of values with asymmetry difference scores. Of these studies, several have reported significant results (Diego, Field, & Hernandez-Reif, 2001; Pauli, Wiedemann, & Nickola, 1999; Wiedemann et al., 1999), whereas others have not (Harmon-Jones et al., 2002; Metzger et al., 2004; Tomarken & Davidson, 1994).

Analytical Considerations

Before discussing important extensions of these studies, a brief word about asymmetry difference scores is in order. Computation of asymmetry difference scores is very common in the frontal EEG and psychopathology literature. Difference scores simplify analyses and control for between-persons variations in skull thickness, which exert considerable effects on the EEG signal (Davidson,

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Jackson, & Larson, 2000). They are limited by their inability to determine which hemisphere is responsible for differences that might exist in resting frontal EEG asymmetry. Individual differences on such a metric could reflect differences in left frontal activity, right frontal activity, or some combination of both. Often, investigators seek to make precisely the hemisphere-specific inferences that asymmetry difference scores do not permit. For instance, some researchers have asserted that depression should be marked more by a deficit in left frontal activity than by an excess in right frontal activity (e.g., Allen, Harmon-Jones, & Cavender, 2001). Analytic procedures that are capable of parsing unique contributions from each hemisphere are available (Coan & Allen, 2003; Kline, Blackhart, & Joiner, 2002; Wheeler, Davidson, & Tomarken, 1993; see Allen et al., 2004, for a review). However, the majority of studies currently under review have reported only results of analyses involving asymmetry difference scores or related indexes of asymmetry. As a result, inferences are made in this report regarding activity in one hemisphere relative to activity in the opposite hemisphere (e.g., *relative right-sided frontal activity* denotes greater right than left frontal activity).

Resting Frontal EEG Asymmetry and Clinical Depression

A key extension of studies examining psychometrically defined depressive symptoms and resting frontal EEG asymmetry involves comparisons of clinically diagnosed depressed individuals with non-ill controls. Several studies have shown that the two groups exhibit the expected frontal asymmetrical differences (Baehr, Rosenfeld, Baehr, & Earnest, 1998; Bell, Schwartz, Hardin, Baldwin, & Kline, 1998; Debener et al., 2000; Gotlib, Ranganath, & Rosenfeld, 1998; Henriques & Davidson, 1991). Once again, however, null results have been obtained (Bruder et al., 1997; Kentgen et al., 2000; Reid et al., 1998).

Resting Frontal EEG Asymmetry in Infants of Depressed Mothers

Infants of depressed mothers show greater relative right-sided frontal activity than infants of nondepressed mothers. These frontal EEG differences are robust for newborns (Diego et al., 2004; Field, Diego, Dieter, et al., 2004; Jones et al., 1998) up to 13- to 15-month-old infants (Dawson, Frey, Panagiotides, Osterling, & Hessl, 1997). The causal mechanism underlying the abnormal patterns of resting frontal EEG asymmetry among infants of depressed mothers is presently unclear. Heritable influences, a suboptimal intrauterine environment, depressogenic mother–infant interactions after birth, or some combination of these may be at work (see Goodman & Gotlib, 1999).

Resting Frontal EEG Asymmetry and Anxiety

Research has shown that resting frontal EEG asymmetry is not linked exclusively to depression but is also linked to other emotion-related disturbances, such as anxiety. There is some evidence that the various subtypes of anxiety (e.g., panic vs. worry) have different implications for resting frontal asymmetry (Heller, Nitschke, Etienne, & Miller, 1997). Nonetheless, the withdrawal motivational and/or negative affective functions of the right frontal cortex suggest that anxious individuals should show a pattern of greater relative right-sided frontal activity, compared with their nonanxious counterparts. Data exist to support this view. People with social phobia (Davidson, Marshall, Tomarken, & Henriques, 2000) and panic disorder patients (Wiedemann et al., 1999) show greater relative right-sided frontal activity compared with non-ill controls. Resting frontal EEG asymmetry correlates significantly with state or trait measures of anxiety (e.g., Petruzzello & Landers, 1994; Tomarken & Davidson, 1994; Wiedemann et al., 1999). As with the depression studies, however, null results have emerged (Kentgen et al., 2000; Nitschke et al., 1999). One study even showed that high scorers on the Trait form of the State–Trait Anxiety Inventory (Spielberger, Gorsuch, & Lushene, 1970) showed greater left than right resting frontal asymmetry (Heller et al., 1997). Finally, three studies have explored relations between comorbid depression and anxiety, on the one hand, and resting frontal EEG asymmetry, on the other. Two of these studies reported null results (Kentgen et al., 2000; Nitschke et al., 1999). The third found that comorbid participants, but not participants with depression only, showed greater relative right-sided frontal asymmetry compared with controls (Bruder et al., 1997).

Null Findings

As noted throughout the preceding sections, not all studies have reported differences between depressed and/or anxious individuals and controls with respect to resting frontal EEG asymmetry. Inconsistencies in the depression literature are particularly apparent. Reasons for these discrepancies are unclear, although speculative explanations have been advanced (Davidson, 1998b). It is possible that certain characteristics of the studies under review (e.g., sample demographic characteristics, depression measurement approaches, EEG recording procedures) may help reconcile inconsistencies in the literature. As yet, a systematic evaluation of these potential moderators has not been carried out.

The Current Study

The purpose of this meta-analysis is three-fold. First, we compared the magnitude of average effects associated with (a) investigations of depressed and nondepressed adults with respect to resting frontal EEG asymmetry and (b) analogous investigations of infants of depressed and nondepressed mothers. Second, in an effort to help reconcile inconsistent findings, we tested a number of moderator variables for their utility in predicting the magnitude of effects across studies. Third, it is presently unclear whether effects obtained from anxious and comorbid samples are comparable in magnitude to those found in depressed samples. A final aim of the present study is to meta-analyze studies of resting frontal EEG asymmetry and (a) anxiety and (b) comorbid depression and anxiety. We used pairwise comparisons to evaluate differences in mean effect sizes across the three sets of studies, hereafter referred to as the *depression studies,* the *anxiety studies,* and the *comorbid stud-*

ies.[1] Given the very small size of the latter two meta-analytic databases, we did not conduct moderator analyses of the same variables investigated in the larger depression database.

Moderator Analyses—Depression Database

Operationalization of Depression

Three operationalizations of depression were examined. The first compared clinically diagnosed depressed individuals and nonill controls with respect to resting frontal EEG asymmetry. The second compared high and low scorers on a validated measure of depression with respect to resting frontal EEG asymmetry.[2] The third correlated the full range of values on a depression measure with a frontal asymmetry difference score. Average effect sizes were computed separately for each of the operationalizations, and differences among them were tested for statistical significance.

Reference Scheme

Asymmetry investigators seek to make inferences regarding activity at single scalp sites. The EEG, however, permits only the evaluation of the difference in electrical activity between a target site and a separate reference site. Researchers have sought to identify an electrically inactive reference, which would allow for unambiguous registration of activity at the target site (target site activity □ zero □ target site activity). An electrically neutral site, however, does not exist (Davidson, Jackson, & Larson, 2000). Although investigators have advanced empirical and theoretical arguments for or against certain reference schemes (e.g., Hagemann, Naumann, & Thayer, 2001; Tucker, 1993), no consensus exists as to which should be preferred. The choice of EEG reference remains one of the most persistent controversies in EEG asymmetry research.

The common vertex (Cz) reference is the most common and potentially troubling scheme used in frontal asymmetry research. As a cephalic site, Cz is highly electrically active. Empirical evaluations of the convergent validity of various reference schemes have shown the Cz reference to be least related to other schemes (Hagemann et al., 2001; Reid et al., 1998). One may derive a less electrically active reference by physically linking the ear or mastoid sites. Alternatively, one may derive an averaged ears or mastoids reference by computing the average activity at the ear or mastoid sites offline. Both approaches yield nearly identical asymmetry estimates (Miller, Lutzenberger, & Elbert, 1991; Senulis & Davidson, 1989). The average reference was used in a handful of the studies reviewed here. At least two conditions are required to derive a reasonably inactive average reference: (a) whole-head sampling with at least 20 electrodes (e.g., Davidson, Jackson, & Larson, 2000), and (b) an even distribution of those electrodes across the surface of the scalp. When these conditions are met, the average voltage of sampled scalp sites should approximate zero. Finally, two studies (Bruder et al., 1997; Kentgen et al., 2000) used a nose reference.

Correlations between reference schemes are modest for the frontal scalp sites examined most frequently in investigations of EEG asymmetry and emotion-related variables (Hagemann, Naumann, Becker, Maier, & Bartussek, 1998; Hagemann et al., 2001; Reid et al., 1998). It remains unclear which scheme is best adapted to the task of uncovering links between frontal cortical asymmetries and emotional pathology. This meta-analysis will inform the reference controversy by documenting the magnitude of average effects associated with each scheme. The analysis may also be useful in determining whether certain reference schemes are associated with significantly heterogeneous effects across studies. It has been speculated, for instance, that the Cz reference may yield the most variable results across studies (Allen et al., 2004).

Scalp Site

Another troublesome issue in EEG asymmetry research concerns the frontal scalp sites at which effects are uncovered. Jacobs and Snyder (1996), for instance, found the predicted relation between Beck Depression Inventory scores and resting asymmetry for lateral frontal but not mid-frontal electrodes. Conversely, several studies have shown very strong relations between mid-frontal asymmetry and depression. In light of the conflicting data, the meta-analysis will compare average effects associated with the various frontal scalp sites.

Gender

There is evidence that gender may modulate hemispheric EEG asymmetry (Bryden, 1982). In addition, Bruder et al. (2001) demonstrated that resting EEG asymmetry predicted response to a selective serotonin reuptake inhibitor for women but not for men. Thus, there is an empirical basis for speculating that depression-related outcomes are more closely linked to resting EEG asymmetry for women than for men. Prediction of effect sizes by the percentage of female participants in the overall sample was assessed.

Resting EEG Length

There was considerable variability across studies in the length of the resting EEG recording period used to approximate trait levels of resting frontal EEG asymmetry. There are at least two reasons to speculate that longer recording periods would be associated with larger effects. First, a longer recording period may enhance sta-

[1] We acknowledge a certain imprecision in the terms used to label the three separate sets of studies. The imprecision is particularly salient when one considers the "depression" and "comorbid" studies. In fact, it would be misleading to draw a sharp distinction between the two. Comorbid studies represent those in which depression and anxiety were documented to co-occur. In the vast majority of depression studies, anxiety was not measured. This leaves open the possibility that many participants in such studies presented with anxiety that was obscured by the explicit focus on depression. This seems eminently likely, given the well-known overlap between symptoms of depression and anxiety (Maser & Cloninger, 1990). Accordingly, data from anxiety studies cannot generally argue for a unique link between resting frontal EEG asymmetry and anxiety, given unaccounted-for shared variance with depression. We invoke the labels out of convenience only; they are not meant to imply clear and unambiguous boundaries between the three sets of studies subjected to separate meta-analyses. In light of these concerns, readers should exercise interpretative caution when evaluating differences in mean effect sizes across the three sets of studies.

[2] For simplicity's sake, when we make reference to comparisons of depressed and nondepressed groups, this includes comparisons of high and low scorers on a validated measure of depressive symptoms.

bility and reliability of measurement, which may, in turn, decrease within-group error variance and increase statistical power to detect between-groups differences. Likewise, the increased reliability typically associated with longer sampling periods may provide a more valid estimate of resting frontal asymmetry. Conversely, it has been argued that the overall length of the recording period is less important than the number of separate blocks used to obtain the asymmetry estimate (Allen et al., 2004). The moderator for resting EEG length evaluated whether the overall length of the recording period was related to effect sizes across studies.

Medication Status

Studies in the meta-analytic database also differed widely with respect to psychoactive medication usage by clinically depressed participants. Such medications may alter certain characteristics of the EEG (Niedermeyer & Lopes da Silva, 1999; Thau et al., 1988). The moderator analysis explored whether greater medication usage on the part of clinically depressed participants predicted effect sizes.

Age

Given that neither theory nor research has offered a reason why younger or older samples should produce larger or smaller effects, the moderator analysis for the mean age of study samples was purely exploratory.

Method

Literature Search

We conducted an exhaustive literature search of the PsycINFO (1887–2006) and MEDLINE (1965–2006) databases by using all relevant combinations of the following keywords: *EEG*, *electroencephalography*, *asymmetry*, *depression*, *depressed mood*, *depressive disorder*, *anxious*, and *anxiety*. The reference list from one recent narrative review of EEG asymmetry and psychopathology (Coan & Allen, 2004) turned up additional articles. Finally, we searched reference lists from articles obtained using both of the other means for additional citations pertinent to the current study. Studies published by May 2006 were included in the meta-analysis.

Inclusion Criteria

Studies were required to meet all of the criteria outlined in this section. First, the study was published in an English-language, peer-reviewed journal. Second, the study contained sufficient information to permit basic description and calculation of effect sizes, or key information absent from the published article was obtained through contact with corresponding authors. Third, the study included concurrent measures of resting frontal EEG asymmetry and depression and/or anxiety. Fourth, acceptable operationalizations of depression and/or anxiety fell into three broad categories: (a) comparison of individuals who met formal diagnostic criteria for a depressive and/or anxiety disorder with non-ill controls; (b) extreme high and low scores on a validated depression or anxiety instrument, which were used to classify participants into groups; or (c) a continuous assessment of depression or anxiety across the entire range of scores on such an instrument. Alternatively, studies examining infants of mothers assessed by one of these means were also included. Studies of older children of depressed and nondepressed mothers (e.g., adolescents; see Tomarken, Dichter, Garber, & Simien, 2004) were excluded unless the older children completed a depression assessment. Given that (a) children as young as preschool age are subject to roughly the same *Diagnostic and Statistical Manual of Mental Disorders*, 4th edition (American Psychiatric Association, 1994) criteria as are adults and (b) adolescent depression is phenomenologically similar to adult depression (Lewinsohn & Essau, 2002), it was judged that older children should be classified as adults in the current analysis. Sole reliance on the mother's depression status would not permit such a classification. For the two group-based measurement approaches, only studies that used currently depressed and/or anxious participants were included. To preserve homogeneity with respect to clinical status across studies in the meta-analytic database, we excluded studies comparing remitted depressives with non-ill controls (e.g., Henriques & Davidson, 1990). One alternative strategy, computing separate effect sizes for both types of studies and evaluating them for differences using moderator analyses, was ruled out because of the very small number of remission studies. Fifth, the study reported EEG data for power in the alpha frequency band at one or more pairs of frontal electrodes. The literature search turned up 31 articles that yielded 59 separate tests of the hypothesis that depressed participants (or their infant children) exhibit greater relative right-sided frontal EEG activity than nondepressed participants.[3] Three of these articles reported separate comparisons of comorbid depressed and anxious participants with controls. Eight articles examining resting frontal EEG asymmetry and anxiety met full inclusion criteria.

Parietal Asymmetry

In the current study, we adopted a selective focus on frontal areas that are presumably involved in the emotional disruptions that characterize depression and/or anxiety. However, standard EEG recording procedures permit investigation of asymmetries all across the scalp. Of note, some studies have uncovered effects at other scalp sites. Henriques and Davidson (1990), for instance, found that remitted depressives exhibited relatively less right-sided activity in posterior temporal, central, and parietal regions than never-depressed controls. Heller et al. (1997; Heller & Nitschke, 1998) have linked asymmetries in parietotemporal regions to differences in arousal, which may have implications for both depression and anxiety.

Most of the studies currently under review collected resting EEG data for at least one pair of frontal electrodes and the parietal electrodes (P3/4). However, of the 31 studies in the depression database, only 11 (35.5%) reported information sufficient to compute a parietal asymmetry effect size. Average effects derived from such a small and probably systematically biased segment of the larger depression database would almost certainly provide a poor approximation of the "true" effect. Accordingly, only 2 of 3 (66.7%) comorbid studies and 4 of 8 (50.0%) anxiety studies reported sufficient parietal data. After exploring the feasibility of including analyses for parietal and other scalp sites, we ultimately proceeded with a singular focus on frontal sites, for which complete data were available in nearly all cases.

Recorded Variables

For each of the statistical tests, the following information was coded for descriptive purposes, moderator analyses, or effect size computation: (a) publication information (authors, year, journal, article title), (b) participant information (sample sizes, age, gender), (c) the percentage of clinically depressed participants taking psychoactive medication at the time of the EEG recording, (d) length of resting EEG recording, (e) operationalization of depression and/or anxiety, (f) reference scheme, (g) scalp sites, and (h)

[3] The discrepancy between the number of articles and the number of separate hypothesis tests is attributable to several articles reporting data for (a) multiple studies, (b) multiple reference schemes, (c) multiple pairs of frontal electrodes, (d) depressed and nondepressed mothers and their infant children, or (e) some combination of these.

information related to the magnitude of the effect of depression and/or anxiety on resting frontal EEG asymmetry (e.g., statistical tests, *p* values, means, and standard deviations). Two trained coders recorded all information independently and achieved over 98% agreement. Coding discrepancies were discussed and resolved by consensus.

Statistical Analysis

Effect size computations. Meta-analytic techniques outlined in Rosenthal (1991) were used. The effect size *r* was calculated for each study to capture the magnitude of resting frontal EEG asymmetry differences between depressed and/or anxious and healthy participants. Higher effect sizes were indicative of a stronger relation between resting frontal EEG asymmetry and depression and/or anxiety in the expected direction (more relative right-sided frontal activity for depressed or anxious participants). In instances in which authors reported only that a given result was nonsignificant, thus omitting information needed to calculate an effect size, the conservative approach of assuming *r* to equal zero was used. All computations involving effect size *r* estimates were performed with Fisher's *r*-to-*z* transformation. Fisher's transformation is considered more suitable for computations because it is distributed nearly normally, whereas *r* is skewed at the upper end of its distribution. Fisher's *z* was transformed back to *r* on completion of statistical operations.

We computed weighted effect sizes by multiplying each individual effect size *r* by its corresponding sample size (Hedges & Olkin, 1985; Rosenthal, 1991). We report mean weighted effect sizes to summarize the magnitude of effects associated with certain groupings of studies (e.g., depression, comorbid, anxiety) that we formed to address the aims of the meta-analysis. We constructed 95% confidence intervals (CIs) around mean weighted effect sizes. If these intervals did not include zero, then we rejected the null hypothesis of no effect. When appropriate, we evaluated variation around mean weighted effect sizes with diffuse comparisons, which are test statistics that are distributed as chi-squares with $k - 1$ degrees of freedom (where k = the number of independent effect sizes on which the analysis was based). Test statistics that exceeded the critical value at $p = .05$ reflected statistically significant heterogeneity in effect sizes. Fail-safe numbers accompany reporting of mean weighted effect sizes. These statistics represent the number of additional studies averaging null results that would be required to bring the significance level of a given combination of studies down to a specified level ($p = .05$ for the current study).

For studies that conducted multiple tests of the same hypothesis (typically because of reporting of data for different reference schemes and/or scalp sites), these tests were initially averaged so that each study contributed only one effect size to the overall analysis. For purposes of moderator analyses, however, these effect sizes were kept separate (see the *Moderator analyses* section).

Moderator analyses. The most straightforward approach to the analysis of categorical moderator variables is to directly compare mean weighted effect sizes for the different subgroups of studies that represent different levels of the categorical moderator (Rosenthal & DiMatteo, 2001). The moderators for *operationalization of depression*, *reference scheme*, and *scalp site* were analyzed in this manner. Differences in mean weighted effects among the three operationalizations were evaluated for statistical significance with pairwise comparisons. Formal significance testing was not used to evaluate differences in mean weighted effects across levels of either the scalp site or the reference scheme moderator. Because several studies reported data for multiple scalp sites (Harmon-Jones et al., 2002; Jacobs & Snyder, 1996; Nitschke et al., 1999; Tomarken & Davidson, 1994), reference schemes (Bruder et al., 1997; Henriques & Davidson, 1991), or both (Reid et al., 1998), meta-analytic assumptions regarding nonindependence of effect sizes would be violated by such analyses (Hedges & Olkin, 1985). Nonetheless, one may more informally assess differences by examining the degree of overlap in the 95% CIs that were constructed around the mean weighted effect sizes that composed each level of the categorical moderators. All other moderator variables were measured on a continuous metric. For these, orthogonal contrast coefficients that captured the variability in the continuous moderator were used to obtain contrast *z* statistics (Rosenthal, 1991), which permitted evaluation of the statistical probability that values of the continuous moderator covaried with study effect sizes. Once again, moderator analyses on the comorbid and anxiety databases were not conducted because of the databases' small size.

Results

Participant Demographics

The depression, comorbid, and anxiety meta-analyses were based on a total of 2,761 participants (1,673 adults, 1,088 infants), 77.9% of whom were female. The mean age of adult participants was 24.4 years (range = 12–64), and the mean age of infant participants was 3.9 months (range = newborn–17 months). Most participants were Caucasian. Tables 1, 2, and 3 display all information coded from the depression, comorbid, and anxiety studies, respectively. Forest plots of individual study effect sizes and 95% CIs are displayed in Figures 1 (depression), 2 (comorbid), and 3 (anxiety). CIs are asymmetrical because of skewness in the *r* distribution.

Mean Weighted Effect Sizes

The left side of Table 4 shows mean weighted effect sizes for adult ($r = .26$, $d = 0.54$) and infant ($r = .29$, $d = 0.61$) depression samples, which were not significantly different ($p = .09$). Both mean weighted effects were significantly different from zero and of moderate magnitude according to effect size conventions (Cohen, 1988). Table 5 summarizes results of analyses involving adult depression ($k = 26$), comorbid ($k = 3$), and anxiety ($k = 8$) studies. The mean weighted effect size of comorbid studies ($r = .08$, $d = 0.16$) was not significantly different from zero. In contrast, the mean weighted effect size for anxiety studies ($r = .17$, $d = 0.35$) did differ from zero. The mean weighted effect size of adult depression studies was significantly larger than that of comorbid studies ($p = .05$). All other pairwise comparisons failed to achieve statistical significance. Of note, however, when one outlier was removed from the anxiety database ($r = .30$; Heller et al., 1997), the difference in mean weighted effect sizes between the anxiety and comorbid studies approached significance ($p = .09$).[4]

[4] It should be mentioned that significance tests involving comparisons of (a) adult and infant depression studies and (b) adult depression, comorbid, and anxiety studies were conducted in violation of the independence assumption discussed earlier. Several studies permitted computation of multiple effect sizes reflecting comparisons of non-ill controls with depressed, comorbid, and/or anxious individuals. In these instances, the same control group was used in the multiple comparisons. In other studies, a single sample of participants completed depression and anxiety measures, both of which were correlated with resting frontal EEG asymmetry and reported individually. In addition, several studies reported data for depressed and nondepressed mothers and their infant children. These analyses were conducted and reported because they directly addressed the primary aims of the study. However, interpretive caution is advised in light of the independence violations.

Table 1
Information Coded From Depression Studies in the Meta-Analytic Database

Study	*n*	Male/female participants	Age	% medicated	Study type	Baseline length (m)	Depression assessment	Scalp site	Reference scheme	*r*	*d*
Baehr et al. (1998)	24		43.8	30.8	A	5	Diag	F3/4	Cz	.59	1.46
Bell et al. (1998)	19	0/19	39.0	70.0	A	1	Diag	F3/4	LE	.42	0.93
Blackhart et al. (2006)	28	5/23	18.8	0	A	6	Cont	Comp.	AE	.27	0.56
Bruder et al. (1997)	51	25/26	37.0	0	A	6	Diag	Comp.	Cz	.01	0.02
									Nose	.10	0.19
Dawson et al. (1992)	27	11/16	14.1 m		I	1	Ext	F3/4	Cz	.00[a]	0.00
Dawson et al. (1997)	117	65/52	13.7 m		I	1	Diag	F3/4	LM	.26	0.54
Debener et al. (2000)	37	12/25	47.0	93.3	A	8	Diag	Comp.	LE	.30	0.63
Deldin & Chiu (2005)	33	8/25	39.4	20.0	A	6	Diag	F3/4	Cz	.04	0.07
Diego et al. (2001)	143	0/143	23.0	0	A	3	Cont	F3/4	Cz	.58	1.42
Diego et al. (2004)	35	17/18	1.7 w	0	I	3	Ext	F3/4	Cz	.58	1.42
Diego et al. (2006)[b]	66	21/45	9.4 w	0	I	3	Cont	F3/4	Cz	.49	1.12
Field et al. (1995)[c]	32	0/32	17.5	0	A	3	Diag	F3/4	Cz	.44	0.98
	32	16/16	4.8 m	0	I	3	Diag	F3/4	Cz	.36	0.77
Field et al. (2000)[b,c]											
Sample 1	192.5	0/192.5	17.7	0	A	3	Ext	F3/4	Cz	.19	0.39
	192.5		4.3 m	0	I	3	Ext	F3/4	Cz	.19	0.39
Sample 2	209	0/209	17.6	0	A	3	Ext	F3/4	Cz	.20	0.41
	209		3.0 m	0	I	3	Ext	F3/4	Cz	.21	0.43
Field, Diego, Dieter, et al. (2004)[c]	119	0/119	25.8	0	A	3	Ext	F3/4	Cz	.33	0.71
	119	52/67	Newborn	0	I	3	Ext	F3/4	Cz	.30	0.62
Field, Diego, Hernandez-Reif, et al. (2004)[c]	92	0/92	29.0	0	A	3	Cont	F3/4	Cz	.28	0.58
	92		Newborn	0	I	3	Cont	F3/4	Cz	.39	0.85
Gotlib et al. (1998)	77	0/77	19.0[d]		A	8	Diag	F3/4	Cz	.30	0.63
Harmon-Jones et al. (2002)	67	34/33	19.0[d]	0	A	8	Cont	Fp1/2	AE	.00[a]	0.00
								F3/4		.00[a]	0.00
								F7/8		.00[a]	0.00
								FT7/8		.00[a]	0.00
								FC3/4		.00[a]	0.00
Henriques & Davidson (1991)	28	11/17	40.5	31.3	A	1	Diag	F3/4	Cz	.45	1.02
									AR	.42	0.91
									AE	.15	0.31
Jacobs & Snyder (1996)	40	40/0			A	5	Cont	F3/4	LE	.00[a]	0.00
								F7/8		.37	0.80
Jones et al. (1997)[c]	40	0/40	18.6	0	A	3	Diag	F3/4	Cz	.38	0.82
	41	20/21	1.0 m	0	I	3	Diag	F3/4	Cz	.31	0.65
Jones et al. (1998)	58	31/27	1.0 w	0	I	3	Diag	F3/4	Cz	.38	0.82
Jones et al. (2001)	38	22/16	10.2 m	0	I	3	Diag	F3/4	Cz	.37	0.80
Jones et al. (2004)[b]	61.5	32/30	1.9 m		I	5–6	Cont	F3/4	Cz	.30	0.63
Kentgen et al. (2000)	18	0/18	15.5	0	A	6	Diag	Comp.	Nose	.08	0.17
Metzger et al. (2004)	42	0/42	53.7	0	A	6	Cont	F3/4	LE	.20	0.41
Nitschke et al. (1999)	25	9/16	18.5	0	A	8	Ext	F3/4	AM	.04	0.08
								F7/8		□.05	□0.09
Pauli et al. (1999)	8	3/5	23.6	0	A	4	Cont	F3/4	LE	.50	1.15
Reid et al. (1998)											
Sample 1	36	0/36	18.6	0	A	8	Ext	F3/4	Cz	.00[a]	0.00
									LM	.00[a]	0.00
									AR	.00[a]	0.00
								F7/8	Cz	.00[a]	0.00
									LM	.00[a]	0.00
									AR	.00[a]	0.00
Sample 2	27	0/27	27.5	0	A	8	Diag	F3/4	Cz	.00[a]	0.00
									LM	.00[a]	0.00
									AR	.00[a]	0.00
								F7/8	Cz	.00[a]	0.00
									LM	.00[a]	0.00
									AR	.00[a]	0.00

Table 1 (*continued*)

Study	*n*	Male/female participants	Age	% medicated	Study type	Baseline length (m)	Depression assessment	Scalp site	Reference scheme	*r*	*d*
Schaffer et al. (1983)	15	5/10	19.0[d]	0	A	1	Ext	F3/4	Cz	.27	0.56
Tomarken & Davidson (1994)	84	0/84	19.0[d]	0	A	8	Cont	F3/4	AE	.09	0.18
	42	0/42						F7/8		.28	0.58
Wiedemann et al. (1999)	48	9/39	36.5	13.0	A	4	Cont	F3/4	Cz	.39	0.85

Note. For infant studies, percentage medicated and depression assessment apply to the mother. m = months (for the Age column) and minutes (for the Baseline length column); w = weeks; A = adult study; I = infant study; Diag = comparison of diagnosed depressives and non-ill controls; Cont = continuous assessment of depression correlated with resting frontal electroencephalograph (EEG) asymmetry; Ext = groups formed on the basis of extreme scores on psychometric depression instrument; F3/4 = mid-frontal; Comp. = composite of F3/4 and F7/8 (Kentgen et al., 2000), along with Fp1/2 (Blackhart et al., 2006), FC5/6 (Bruder et al., 1997), or T3/4 (Debener et al., 2000) scalp sites; Fp1/2 = frontal pole; F7/8 = lateral frontal; FT7/8 = frontal temporal; FC3/4 = frontal central; Cz = common vertex; LE = linked ears; AE = averaged ears; LM = linked mastoids; AR = average reference; AM = averaged mastoids.

[a] In instances in which the article reported a given comparison as nonsignificant but omitted information needed to compute an effect size, the conservative approach of assuming $r = .00$ was used. [b] Studies for which data were averaged across repeated measurements at initial and follow-up visits. [c] Studies that reported EEG data for depressed and nondepressed mothers and their infant. [d] In instances in which the article reported only that the study sample was drawn from an undergraduate population, the mean age of participants was estimated to be 19.0 years.

Heterogeneity Tests

Adult depression samples showed significant variation around the mean weighted effect size (see Table 4). Thus, moderator analyses were justified in light of this variability. Infant samples did not show significant heterogeneity around the mean weighted effect size. However, given the small number of infant studies on which the heterogeneity test was based, it is possible that statistical power was insufficient to detect significant variation. Therefore, moderator analyses were carried out in spite of the nonsignificant heterogeneity test for infant samples. Comorbid studies did not show significant variability around the mean weighted effect size. After removal of the Heller et al. (1997) outlier from the anxiety database, the significant variability shown by anxiety studies diminished, $Q^2(6) = 6.71$, $p = .35$.

Moderator Analyses—Depression Database

Operationalization of depression. Some divergence in effect sizes was noted across the three operationalizations (see Table 4). For adult depression samples, studies using the extreme scores approach showed marginally smaller effects than those using the clinical depression ($p = .10$) and continuous assessment ($p = .09$) approaches. For infant depression samples, studies using the extreme scores approach showed marginally smaller effects than those using the continuous assessment approach ($p = .06$).

Reference scheme. To obtain a more reliable assessment of effects, we combined the averaged mastoids, averaged ears, linked mastoids, and linked ears reference schemes to form a single category (A1 = A2). This decision was justified, in part, by the nonsignificant heterogeneity test for the larger A1 = A2 category (see Table 6). The Cz reference yielded the largest effects, followed by A1 = A2, average reference, and nose reference. Overlap among 95% CIs was substantial for all pairs of reference schemes except for Cz and A1 = A2, for which overlap was nearly absent. Of note, only effect sizes for the Cz reference showed significant variability around the mean weighted effect ($p = .001$). All but one infant depression study used the Cz reference, precluding moderator analyses.

Scalp site. Table 7 shows that reporting of data for mid-frontal scalp sites ($k = 22$) was far more common than reporting of either lateral frontal ($k = 6$) or composite frontal ($k = 4$) data. The mean weighted effect for mid-frontal scalp sites was largest, followed by composite frontal and lateral frontal sites, neither of which differed significantly from zero. Minimal overlap in 95% CIs was observed between mid-frontal and all other frontal sites except for the composite. Only mid-frontal sites yielded significantly variable effects ($p = .001$). This was probably attributable, at least in part, to the relatively large number of studies used to compute the mean weighted effect for mid-frontal scalp sites. More data are needed to draw firm conclusions regarding effects at the frontal pole ($k = 1$), frontal temporal ($k = 1$), and frontal central ($k = 1$) sites. Infant depression studies reported data for only the mid-frontal scalp sites.

Gender. For both adults and infants, the percentage of female participants who composed the samples was not related to the magnitude of effects (see Table 8).

Resting EEG length. For adult samples, shorter resting EEG recording periods were associated with larger effects (see Table 8). A similar analysis performed on only infant samples was precluded by a lack of variability in resting EEG length. Infant depression studies overwhelmingly used 3-min EEG recording periods.

Medication status. For adult samples, the percentage of clinically diagnosed depressed participants taking psychoactive medications at the time of the EEG recording was not related to the magnitude of effects (see Table 8). None of the depressed mothers was taking medication at the time of the EEG recording, so a similar analysis was not possible for infant samples.

Age. Although the mean age of adult samples was unrelated to the magnitude of effects, data for infants showed that younger samples yielded larger effects than older ones (see Table 8).

Publication Bias

We constructed a funnel plot (Light & Pillemer, 1984) to assess the degree to which the "file drawer problem" (Rosenthal, 1979),

Table 2
Information Coded From Comorbid Studies in the Meta-Analytic Database

Study	*n*	Male/female participants	Age	% medicated	Study type	Baseline length (m)	Dep/Anx assessment	Scalp site	Reference scheme	*r*	*d*
Bruder et al. (1997)	45	23/22	34.5	0	A	6	Diag	Comp.	Cz	−.09	−0.19
									Nose	.40	0.88
Kentgen et al. (2000)	21	0/21	15.5	0	A	6	Diag	Comp.	Nose	.00[a]	0.00
Nitschke et al. (1999)	26	12/14	18.2	0	A	8	Ext	F3/4	AM	.04	0.08
								F7/8		−.03	−0.06

Note. m = minutes; Dep/Anx = depression/anxiety; A = adult study; Diag = comparison of diagnosed depressed and anxious participants with non-ill controls; Ext = groups formed on the basis of extreme scores on psychometric depression and anxiety instruments; Comp. = composite of F3/4 and F7/8 (Kentgen et al., 2000) or F3/4, F7/8, and FC5/6 (Bruder et al., 1997) scalp sites; F3/4 = mid-frontal; F7/8 = lateral frontal; Cz = common vertex; AM = average mastoids.
[a] In instances in which the article reported a given comparison as nonsignificant but omitted information needed to compute an effect size, the conservative approach of assuming $r = .00$ was used.

Table 3
Information Coded From Anxiety Studies in the Meta-Analytic Database

Study	*n*	Male/female participants	Age	% medicated	Study type	Baseline length (m)	Anxiety assessment	Scalp site	Reference scheme	*r*	*d*
Blackhart et al. (2006)	28	5/23	18.8	0	A	6.0	Cont (STAI–T)	Comp.	AE	.14	0.28
Heller et al. (1997)	40	18/22	19.0[a]	0	A	8.0	Ext (STAI–T)	F3/4	AM	−.30	−0.63
Kentgen et al. (2000)	16	0/16	15.5	0	A	6.0	Diag (PD, SP, PTSD)	Comp.	Nose	.00[b]	0.00
Metzger et al. (2004)	42	0/42	53.7	0	A	6.0	Cont (SCL-90-R Anx)	F3/4	LE	.21	0.43
Nitschke et al. (1999)	32	15/17	18.3	0	A	8.0	Ext (MASQ Anx Aro)	F3/4	AM	.04	0.08
								F7/8		.06	0.12
	22	9/13	18.2	0	A	8.0	(PSWQ)	F3/4		.02	0.04
								F7/8		−.02	−0.04
Petruzzello & Landers (1994)	19	19/0	22.7	0	A	1.1	Cont (STAI–T)	F3/4	Ipsilateral A1, A2	.61	1.54
Tomarken & Davidson (1994)	86	0/86	19.0[a]	0	A	8.0	Cont (STAI–T)	F3/4	AE	.20	0.41
	42	0/42						F7/8		.31	0.65
Wiedemann et al. (1999)	48	9/39	36.5	13.0	A	4.0	Diag (PD)	F3/4	Cz	.33	0.71
							Cont (STAI–T)			.27	0.56
							(SCL-90–R Anx)			.52	1.22

Note. m = minutes; A = adult study; Cont = continuous assessment of anxiety correlated with resting frontal electroencephalograph asymmetry; STAI–T = State–Trait Anxiety Inventory—Trait version (Spielberger et al., 1970); Ext = groups formed on the basis of extreme scores on psychometric anxiety instruments; Diag = comparison of diagnosed depressed and anxious participants with non-ill controls; PD = panic disorder; SP = social phobia; PTSD = posttraumatic stress disorder; SCL-90–R = Symptom Checklist 90—Revised (Derogatis, 1983); Anx = anxiety; MASQ = Mood and Anxiety Symptom Questionnaire (Watson et al., 1995); Anx Aro = anxious arousal; PSWQ = Penn State Worry Questionnaire (Meyer, Miller, Metzger, & Borkovec, 1990); Comp = composite of F3/4 and F7/8 (Kentgen et al., 2000) or F3/4, F7/8, and Fp1/2 (Blackhart et al., 2006) scalp sites; F3/4 = mid-frontal; F7/8 = lateral frontal; AE = averaged ears; AM = average mastoids; LE = linked ears; Ipsilateral A1, A2 = left and right frontal electrodes referenced to left and right mastoids, respectively; Cz = common vertex.
[a] In instances in which the article reported only that the study sample was drawn from an undergraduate population, the mean age of participants was estimated to be 19.0 years. [b] In instances in which the article reported a given comparison as nonsignificant but omitted information needed to compute an effect size, the conservative approach of assuming $r = .00$ was used.

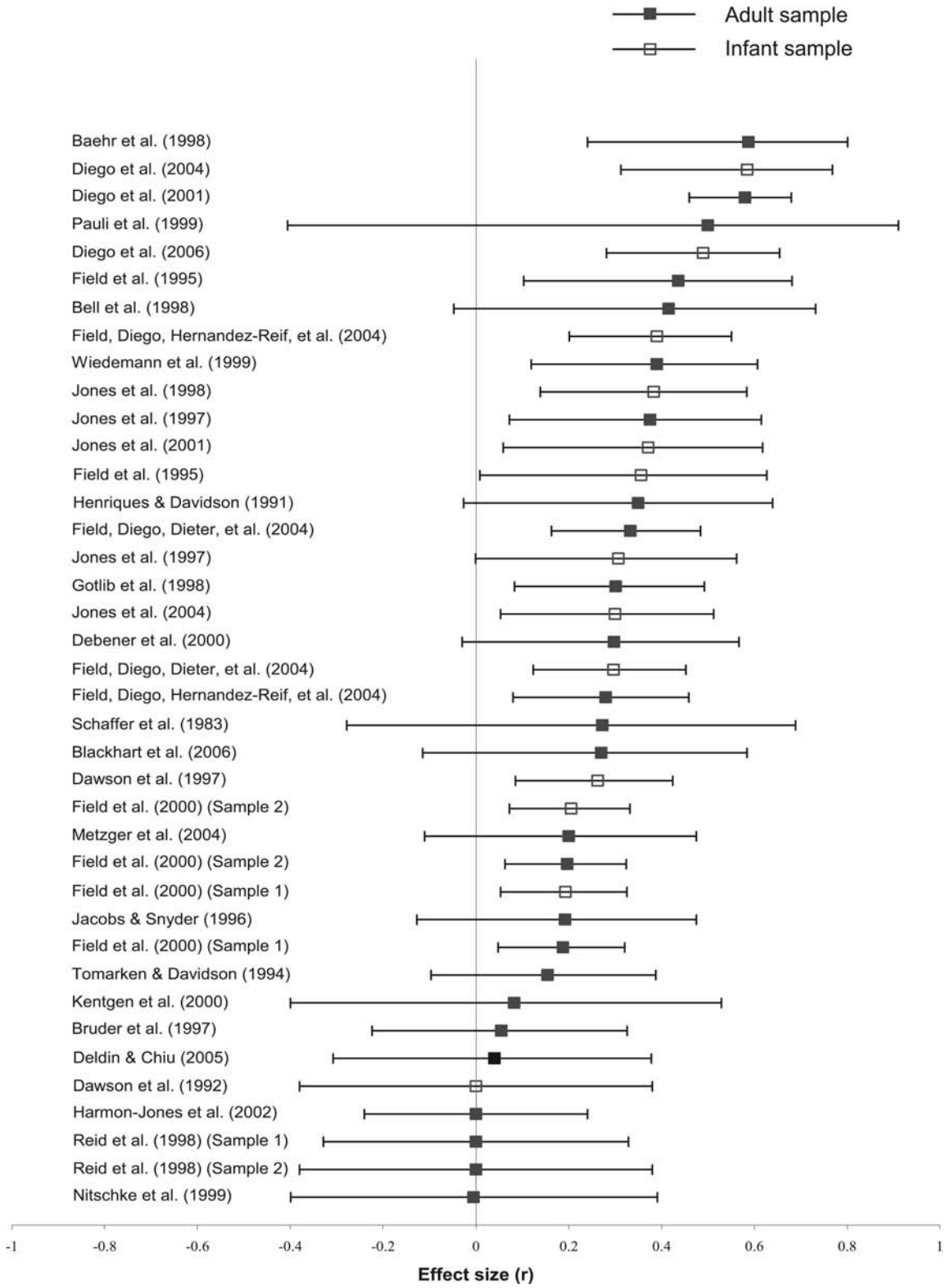

Figure 1. Forest plot representing weighted effect sizes (*r*) and 95% confidence intervals for depression studies in the meta-analytic database.

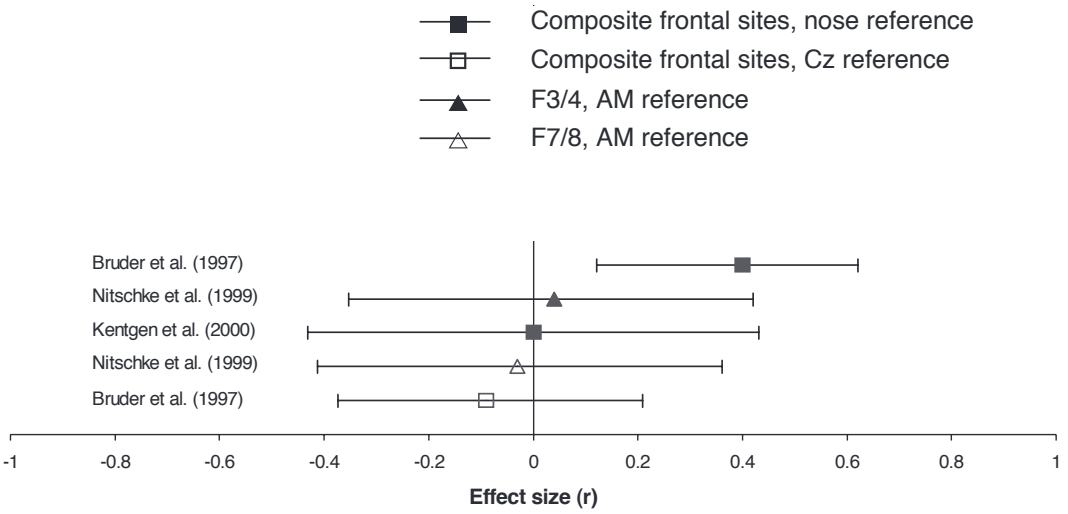

Figure 2. Forest plot representing weighted effect sizes (*r*) and 95% confidence intervals for comorbid studies in the meta-analytic database. Effect sizes are displayed separately by characteristics of the electroencephalograph recording procedure. Cz = common vertex; AM = average mastoids.

or a systematic bias in favor of publishing significant results, might have inflated effect size estimates. In short, small samples should yield substantially variable effects, whereas large samples should yield effect sizes that more closely approximate the true effect. In the absence of publication bias, plotting effect sizes as a function of their respective sample sizes should yield a funnel-shaped figure with a broad base (i.e., substantial variability for small samples) and a tall peak, resulting from convergence of effect sizes on the true effect as sample sizes increase. In the current study, however, a relative lack of data points in the lower left-hand portion of the plot indicated that small samples yielded more large effects than small effects (see Figure 4). A systematic publication bias in favor of significant results might have inflated effect size estimates we report.

Discussion

Results indicate that mean weighted effect sizes were nearly identical for adult and infant depression samples and of moderate magnitude according to effect size conventions (Cohen, 1988). These effects were significantly different from zero. Variability in the magnitude of effects around the weighted mean was noted for adult samples but not for infant samples. After removal of an outlier, the mean weighted effect of studies in the anxiety database approached the magnitude found among the adult and infant depression studies. The mean weighted effect size of studies in the comorbid database was significantly smaller than that for the depression database. Overall, results suggest that both depressive and anxious symptomatology show moderately strong relations

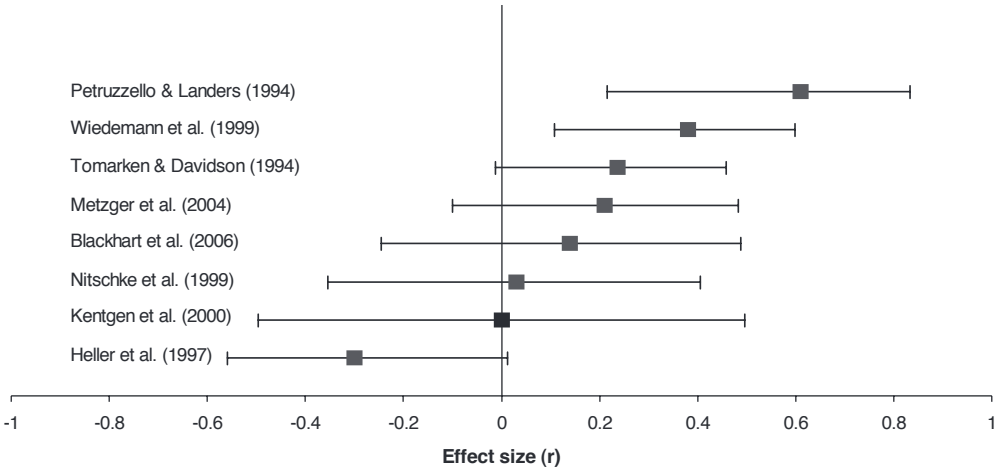

Figure 3. Forest plot representing weighted effect sizes (*r*) and 95% confidence intervals for anxiety studies in the meta-analytic database.

Table 4
Mean Weighted Effect Sizes, 95% Confidence Intervals (CIs), and Heterogeneity Statistics for Adult and Infant Depression Samples, Collapsed Across and Separately by Operationalization of Depression

Sample and statistic	Overall	By operationalization of depression		
		Diag	Ext	Cont
Adult samples				
k	26	11	6	9
Mean weighted *r*	.26	$.27_{a}$	$.20_{b}$	$.32_{a}$
95% CI	.22, .31	.17, .36	.12, .28	.24, .40
χ^2 (*k* − 1)	47.69**	12.06	4.78	26.26***
Failsafe *N*	763	94	32	128
Infant samples				
k	13	5	5	3
Mean weighted *r*	.29	$.32_{a,b}$	$.24_{b}$	$.40_{a}$
95% CI	.24, .35	.21, .42	.16, .31	.28, .50
χ^2 (*k* − 1)	16.11	0.91	8.37	1.57
Failsafe *N*	442	49	54	37

Note. Chi-squares tested the statistical probability that individual effect sizes were significantly heterogeneous around the mean weighted effect. Mean weighted effect sizes that do not share a subscript showed a nonsignificant trend toward differing at $p < .10$. Diag = comparisons of participants meeting formal diagnostic criteria for a depressive disorder and non-ill controls; Ext = participants categorized as depressed or nondepressed on the basis of extreme scores on a validated depression instrument; Cont = scores on a validated depression instrument treated as a continuous variable. *k* = the number of independent effect sizes on which the analysis was based.
** $p < .01$. *** $p < .001$.

with relative right-sided frontal EEG asymmetry. Comorbid data are inconclusive.

A brief word about the comorbid database is in order. First, the finding that comorbid studies yielded smaller average effects than either depression or anxiety studies seems logically untenable. If both depression and anxiety are related to relative right-sided frontal EEG asymmetry, why would the combination of both depression and anxiety not follow this same trend? This curious finding might be attributed to the size of the comorbid database, which is far too small to yield meaningful and reliable conclusions. It is unmistakably premature to suggest that comorbid depression and anxiety bear a weaker relation to resting frontal EEG asymmetry than either depression or anxiety alone. Additional research is needed to fully address this issue. Second, it is worth reiterating that comorbid studies represent only those in which investigators explicitly assessed both depression and anxiety. In the vast majority of depression studies, anxious symptomatology was not measured. Given the shared variance between depression and anxiety (Maser & Cloninger, 1990), a reasonable speculation is that the

Table 5
Mean Weighted Effect Sizes, 95% Confidence Intervals (CIs), and Heterogeneity Statistics for Depression, Comorbid, and Anxiety Studies (Adults Only)

Study type	*k*	Mean weighted *r*	95% CI	χ^2 (*k* − 1)	Failsafe *N*
Depression	26	$.26_{a}$	.22, .31	47.69**	763
Comorbid	3	$.08_{b}$	−.13, .29	0.56	0[a]
Anxiety	8	$.17_{a,b}$	.05, .29	16.78*	13
Outlier removed	7	.25	.12, .37	6.71	26

Note. The outlier was from Heller et al. (1997; $r = -.30$). Mean weighted effect sizes that do not share a subscript are significantly different at $p < .05$. Chi-squares tested the statistical probability that individual effect sizes were significantly heterogeneous around the mean weighted effect. *k* = the number of independent effect sizes on which the analysis is based.
[a] The combined probability level of the comorbid studies already exceeded $p < .05$.
* $p < .05$. ** $p < .01$.

Table 6
Mean Weighted Effect Sizes, 95% Confidence Intervals (CIs), and Heterogeneity Statistics Computed Separately by Reference Scheme (Adult Depression Samples Only)

Reference scheme	*k*	Mean weighted *r*	95% CI	χ^2 (*k* − 1)	Failsafe *N*
Cz	16	.29	.24, .34	39.72***	474
A1 − A2	12	.15	.05, .24	6.67	29
AR	3	.14	−.08, .34	3.48	0[a]
Nose	2	.10	−.15, .33	0.00	0[a]

Note. A1 − A2 includes the linked mastoids, averaged mastoids, linked ears, and averaged ears schemes. Chi-squares tested the statistical probability that individual effect sizes were significantly heterogeneous around the mean weighted effect. *k* = the number of independent effect sizes on which the analysis is based; Cz = common vertex; AR = average reference.
[a] The combined probability levels of studies using the average and nose references already exceeded $p < .05$.
*** $p < .001$.

Table 7
Mean Weighted Effect Sizes, 95% Confidence Intervals (CIs), and Heterogeneity Statistics Computed Separately by Scalp Site (Adult Depression Samples Only)

Scalp site	*k*	Mean weighted *r*	95% CI	χ^2 (*k* − 1)	Failsafe *N*
F3/4	22	.26	.21, .31	48.73***	598
F7/8	6	.11	−.02, .24	6.13	0[a]
Composite	4	.17	−.00, .34	1.67	2
Fp1/2	1	.00	−.24, .24		0[a]
FT7/8	1	.00	−.24, .24		0[a]
FC3/4	1	.00	−.24, .24		0[a]

Note. Chi-squares tested the statistical probability that individual effect sizes were significantly heterogeneous around the mean weighted effect. *k* = the number of independent effect sizes on which the analysis is based; F3/4 = mid-frontal; F7/8 = lateral frontal; Composite = scalp sites that reflect activity at F3/4 and F7/8 (Kentgen et al., 2000); F3/4, F7/8, and FC5/6 (Bruder et al., 1997); F3/4, F7/8, and T3/4 (Debener et al., 2000); or F3/4, F7/8, and Fp1/2 (Blackhart et al., 2006). Fp1/2 = frontal pole; FT7/8 = frontal temporal; FC3/4 = frontal central.
[a] The combined probability levels of studies reporting data for F7/8, Fp1/2, FT7/8, and FC3/4 already exceeded $p < .05$.
*** $p < .001$.

Table 8
Contrast zs for Continuous Moderators Tested in the Meta-Analysis, Separately for Adult and Infant Depression Samples

Moderator	*k*	*z*
	Adult	
Age	25	1.04
Gender	25	0.87
Resting EEG length	26	−2.95**
Medication status	10	1.18
	Infant	
Age	13	−2.02*
Gender	10	0.05

Note. *k* = the number of independent effect sizes on which the moderator analysis is based; Age = mean age of the entire sample; Gender = percentage of female participants in the overall study sample; Resting EEG length = length of resting electroencephalograph (EEG) recording period, in minutes; Medication status = percentage of clinically diagnosed depressed participants taking psychoactive medication at the time of the EEG recording.
* $p < .05$. ** $p < .01$.

mean weighted effect size for depression studies reflects a fair amount of untapped anxiety among study participants. If this is accurate, then comorbid depression and anxiety may bear a stronger relation to resting frontal EEG asymmetry than is suggested by the results.

Results of analyses involving the anxiety database are revealing. After removal of the outlier (Heller et al., 1997; $r = -.30$), the mean weighted effect sizes of adult depression and anxiety studies were shown to be quite similar (*r*s = .26 and .25, respectively). Heller et al.'s (1997) anomalous result may be worth exploring, however. First, it merits mention that their observed positive relation between trait anxiety and relative left-sided frontal activity confirmed a priori predictions. Scores on a trait anxiety measure, Heller et al. reasoned, should be expected to tap worry or anxious rumination instead of anxious arousal (i.e., panic). To the extent that worry or anxious rumination (a) involves a strong verbal component mediated by the left hemisphere and (b) encourages prolonged task engagement (e.g., approach) mediated by left frontal cortical areas, trait anxiety should be associated with relative left-sided, not right-sided, frontal activity. Although this seems reasonable, it is unclear why other studies using trait anxiety measures in the meta-analytic database found the opposite pattern of results (Petruzzello & Landers, 1994; Tomarken & Davidson, 1994; Wiedemann et al., 1999). One possibility is that Heller et al. (1997) recruited only anxious participants who were not concurrently experiencing depressive symptoms. Perhaps high positive correlations reported between trait anxiety and relative right-sided frontal asymmetry in other studies are attributable in large part to depression-related variance. This hypothesis is bolstered by data from other studies in the anxiety database that recruited participants who were symptomatic with respect to anxiety but not depression (Kentgen et al., 2000; Nitschke et al., 1999). In these studies, relations between resting frontal EEG asymmetry and anxiety were near zero.

Overall, the results we report suggest that resting frontal EEG asymmetry may be nonspecifically related to both depression and anxiety. However, this study is ill equipped to optimally address the specificity issue. That is, although studies of depression and anxiety were subjected to separate meta-analyses and similarly sized effects emerged for both, this approach is limited in its ability to assess their independent contributions to frontal asymmetry. This is because most of the original data integrated here failed to account for shared variance between the two. We strongly recommend that future researchers address the specificity issue either (a) methodologically, by recruiting participants who are symptomatic with respect to either depression or anxiety but not both; (b) psychometrically, by using measures that minimize confounding of depression and anxiety; or (c) statistically, by removing shared variance.

Moderator Analyses

Prior to discussing the results of moderator analyses, we should note that the moderators captured a relatively small slice of the variability across studies that may be useful in reconciling the inconsistent pattern of results noted previously. Among the potentially meaningful sources of variability that could not be systematically examined were differences in diagnostic subtypes, symptom features and severity, chronicity, and age of onset. More research is needed to examine the impact of these variables.

Contrary to prediction, shorter resting EEG recording periods were associated with larger effects. It is possible that shorter recording periods contain more state-related negative affect arising from the perceived unpleasantness of the experimental situation. The aversive novelty of the task (e.g., EEG electrode placement and hookup) or interaction with unfamiliar experimenters may unduly bias asymmetry estimates, particularly for depressed participants. As such participants are acclimating to the laboratory context, their frontal asymmetry may regress toward a pattern characteristic of nondepressed individuals. Reid et al. (1998) presented data that were pertinent to this possibility. Using all 8 min of resting EEG data collected, they obtained no differences between depressed and nondepressed participants in two separate studies using orthogonal samples. However, for one of these samples, post hoc analyses revealed that the first 2 min of resting data differentiated depressed and nondepressed participants with respect to lateral frontal asymmetry. Given both the findings regarding baseline length that we report and the data reported by Reid et al. (1998), further exploration of the relation between baseline length and resting frontal EEG asymmetry is in order.

The moderator analysis for reference scheme demonstrates that, across studies, the Cz reference yielded effect sizes that were somewhat larger and more variable than effects obtained with other reference schemes. The latter finding is consistent with Allen et al.'s (2004) suggestion that usage of the Cz reference results in an inconsistent pattern of overall findings regarding resting frontal EEG asymmetry and psychopathology. Use of the Cz reference in asymmetry research appears to be a hit or miss venture; some studies yield very large effects, whereas others yield rather small effects. The other three schemes we explored—A1 = A2 ($r = .15$), average reference ($r = .14$), and nose reference ($r = .10$)—were associated with smaller yet less variable mean weighted effects. Very few studies in the meta-analytic database used the average and nose references, in particular. As such, more data are needed to confirm the preliminary findings reported here.

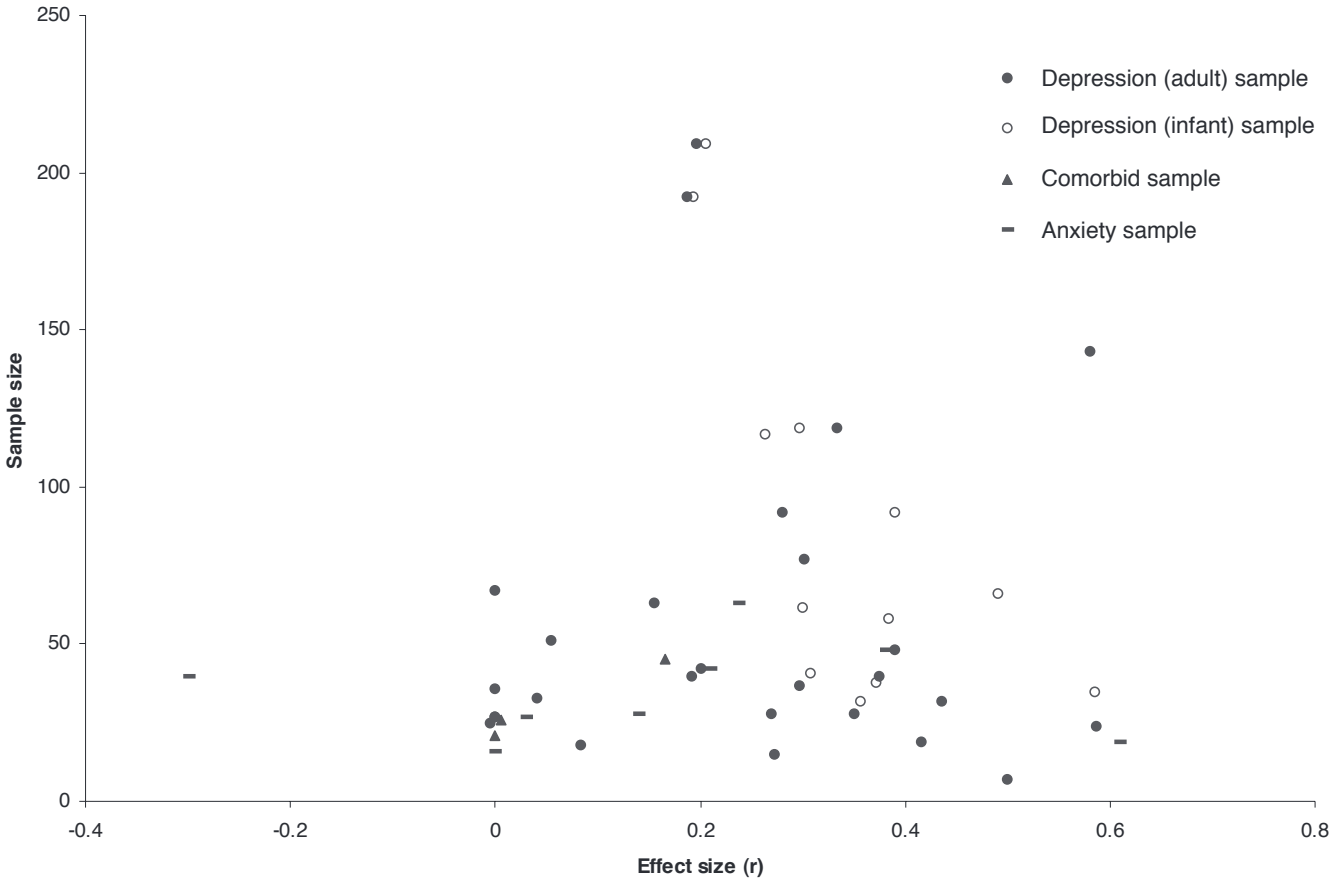

Figure 4. Funnel plot depicting effect size (*r*) as a function of sample size for studies in the depression (adult and infant), comorbid, and anxiety meta-analytic databases. A relative lack of data points in the lower left-hand portion of the plot is suggestive of a systematic publication bias in favor of significant results.

With respect to the scalp site moderator, mean weighted effects associated with the mid-frontal (F3/4) site appeared somewhat larger than either the lateral frontal (F7/8) or the composite frontal mean weighted effects. Only the mid-frontal site was associated with significant variability around the mean weighted effect size. This may be due, in large part, to the substantially greater number of studies that reported data for this site compared with the other two. Indeed, given the very small number of studies using the lateral frontal or composite frontal scalp sites, interpretive caution should be exercised. Although more data are needed to firmly establish that the mid-frontal scalp sites more closely tap depression- or anxiety-related patterns of cortical activity, the present findings may be seen as suggestive. Data for frontal pole, frontal temporal, and frontal central scalp sites are insufficient to permit reasonable inferences.

Finally, moderator analyses revealed that younger infant depression samples yielded larger effects than older ones. First, these data may suggest that maturational or historical factors attenuate the relation between children's resting frontal EEG asymmetry and maternal depression over time. This hypothesis is highly speculative, however. Moreover, invoking within-person developmental processes to interpret the present cross-sectional data is risky. Longitudinal data would be needed to adequately evaluate such a prediction. Second, the effect size associated with the oldest infant sample (Dawson et al., 1992; mean age = 14.1 months) was assumed to be zero because of the lack of required statistical information in the published article. This conservative strategy might have unduly biased the older samples toward smaller effects, thereby exaggerating differences between younger and older infant samples. In fact, when the infant age moderator analysis was repeated after excluding the Dawson et al. (1992) study, it failed to achieve statistical significance ($p = .14$).

Publication Bias

Evidence presented in this article suggests that a systematic publication bias may operate in the resting frontal EEG asymmetry and depression–anxiety literature (see Figure 4). One may question, then, whether any meaningful effect would have emerged in the absence of such a bias. Two points deserve mention. First, although the funnel plot revealed that small samples yielded more large effects than small effects, this trend was not overwhelmingly convincing. Close inspection of the plot shows a cluster of 11 effect sizes around $r = .00$. Publishing of nonsignificant results is not inordinately rare in this literature. Second, the plot suggests that as sample sizes increased, effect sizes converged at around $r = .20$ ($d = 0.41$). Although this estimate is somewhat smaller than the mean weighted effect reported

for both adult and infant depression studies, it nonetheless implies that depressive and anxious symptomatology accounts for a nonnegligible portion of the variance in resting frontal EEG asymmetry. The findings reported here remain consequential even after accounting for systematic publication bias.

Summary and Conclusions

The moderately large effect sizes obtained here suggest that both depression and anxiety are meaningfully related to relative right-sided resting frontal EEG asymmetry. More data are needed to establish the presence or absence of a similar relation involving comorbid depression and anxiety. Although the data suggest that resting frontal EEG asymmetry is nonspecifically related to both depression and anxiety, more research is needed to assess the magnitude of their independent contributions to frontal asymmetry. Among depression studies, moderator analyses involving depression operationalization, length of resting EEG baseline, and age of infant samples provide a partial account of variability in effect sizes across studies. Two EEG procedural variables, reference scheme and scalp site, also explain a small slice of this variability.

References

References marked with an asterisk indicate studies included in the meta-analysis.

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