NOTICE: This material may be protected
By copyright law (Title 17 U.S. Code)

PSYCHOPHYSIOLOGY
Copyright © 1992 by The Society for Psychophysiological Research, Inc.

Vol. 29, No. 5
Printed in U.S.A.

Psychometric Properties of Resting Anterior EEG Asymmetry: Temporal Stability and Internal Consistency

ANDREW J. TOMARKEN,
Vanderbilt University

RICHARD J. DAVIDSON, ROBERT E. WHEELER, AND LINDA KINNEY
University of Wisconsin-Madison

ABSTRACT

We examined whether resting anterior electroencephalographic (EEG) asymmetry in the alpha frequency band has psychometric properties that would be expected of a measure assessing individual differences. In each of two experimental sessions, separated by three weeks, resting EEG in midfrontal and anterior temporal sites was recorded from 85 female adults during eight 60-s baselines. Resting alpha asymmetry demonstrated acceptable test-retest stability and excellent internal consistency reliability. Analyses including other frequency bands indicated that degree of stability varied somewhat as a function of band and region. In addition, asymmetry was less stable than absolute power. Discussion focuses on the implications of the present findings for the measurement and conceptualization of resting anterior asymmetry.

DESCRIPTORS: Asymmetry, Electrophysiology, Electroencephalography, Resting EEG, Stability, Psychometric, Individual differences.

The present study assessed the test-retest stability and other psychometric properties of resting electroencephalographic (EEG) asymmetry recorded from anterior regions of the scalp. Our interest in this issue derived from recent findings of ours indicating that resting anterior EEG asymmetry in the alpha (8–13 Hz) frequency band may be a biological marker of emotional predispositions or traits. This research has shown that relative right hemisphere activation (i.e., alpha suppression) recorded from midfrontal and anterior temporal regions during resting baselines is associated with increased negative affect and decreased positive affect. Conversely, relative left anterior activation at rest has been linked to increased positive affect and decreased negative affect. For example, we have found that resting frontal asymmetry predicts adults' (Tomarken, Davidson, & Henriques, 1990; Wheeler, Davidson, Tomarken, & Kinney, in press) and infants' (Davidson & Fox, 1989) responses to emotion-eliciting stimuli. In addition, we have shown that resting anterior asymmetry is linked to individual differences in affective traits and temperament (e.g., Finman, Davidson, Colton, Straus, & Kagan, 1989; Tomarken, Davidson, Wheeler, & Doss, 1992), to vulnerability for affective disorders (Henriques & Davidson, 1990), and to immunological functioning (Kang et al., 1991) (for reviews, see Davidson, in press; Davidson & Tomarken, 1989).

If resting anterior asymmetry is indeed a measure of individual differences, then, almost by definition, it should be stable over time. In addition, just as separate items on a scale designed to assess a personality trait should significantly covary, different measures of resting anterior asymmetry assessed on one occasion should covary. In other words, these measures should demonstrate adequate internal consistency reliability (e.g., Lord & Novick, 1968; Nunnally, 1978).

Unfortunately, to our knowledge, no studies to date have directly assessed the test-retest stability and other psychometric features of resting anterior EEG asymmetry in the alpha band or in other frequency bands. Several studies in recent years have,

The present study was supported by NIMH grants MH40747 and MH43454, by an NIMH Research Scientist Development Award (MH00875) to Richard J. Davidson, and by NIMH post-doctoral fellowship MH09678 to Andrew Tomarken. The authors would like to thank Andrea Straus, Rob Doss, Joseph Senulis, Cliff Saron, and Greg Arko for their help in various phases of this research.

Address requests for reprints to: Andrew J. Tomarken, Department of Psychology, 301 Wilson Psychology Building, Vanderbilt University, Nashville, TN 37240; or to Richard J. Davidson, Department of Psychology, University of Wisconsin-Madison, 1202 West Johnson Street, Madison, WI 53706.

however, demonstrated that measures of absolute and relative *EEG power* in specific sites demonstrate excellent test-retest stability over time. Particularly good stability has been shown for measures of alpha power in both anterior and posterior sites (Fein, Galin, Yingling, Johnstone, & Nelson, 1984; Gasser, Bacher, & Steinberg, 1985; Lynch, Paskewitz, & Orne, 1974; Pollock, Schneider, & Lyness, in press; Van Dis, Corner, Dapper, Hanewald, & Kok, 1979). In addition, several studies have found high levels of concordance among power measures assessed on a single occasion from anterior and/or other sites (Gasser et al., 1985; Oken & Chiappa, 1988; Stassen, 1980; cf. Matousek, Arvidsson, & Friberg, 1979).

In the present context, however, one significant limitation of these previous studies is that the stability of EEG *power* does not necessarily imply the stability of EEG *asymmetry*. Indeed, despite the fact that measures of power are used in the calculation of asymmetry, we have typically found that power and asymmetry measures are only weakly correlated (e.g., *r*'s in the −.20 to .20 range). This observation follows directly from the fact that asymmetry is typically computed as the difference between power values in homologous sites, and from two statistical characteristics of power measures. Concerning the latter, power measures in homologous sites are usually highly correlated (e.g., *r*'s in the .90 range are not uncommon), and the variances of such power measures are usually at least roughly equal. Under these conditions, it can be shown that correlations between a measure (e.g., power) and a difference score involving that measure (e.g., asymmetry) are mathematically constrained to be of low magnitude.

The low correlation between power and asymmetry measures highlighted the need for direct assessment of the stability of resting anterior EEG asymmetry. Ehrlichman and Wiener (1979) have previously shown that resting EEG asymmetry in posterior (parietal-temporal) sites is stable over time (test-retest $r=.74$ over a three-week interval; see also Amochaev & Salamy, 1979; Dabbs & Chou, 1980; Morgan, McDonald, & MacDonald, 1971). On the basis of these results, and our recent findings suggesting that resting anterior asymmetry may be a marker of individual differences, we predicted that measures of resting anterior EEG asymmetry would demonstrate good test-retest stability over time. In addition, we predicted that resting asymmetry measures assessed during separate resting baselines within a given session would demonstrate appropriately high levels of internal consistency.

To test these predictions, we recorded resting EEG from adult subjects across two occasions, separated by three weeks. During each session, eight 1-min baselines of resting EEG were recorded from the two anterior sites (midfrontal and anterior temporal) that have been linked to individual differences in emotional style in our previous individual difference studies. Below, we report the test-retest stability of resting measures of both absolute power and asymmetry in the alpha band and other bands. We also report the within-session internal consistency reliability of resting alpha asymmetry, and several of its additional psychometric properties.

Method

Subjects

Subjects were 90 right-handed undergraduate females aged 17–21 years, recruited from the Introductory Psychology pool at the University of Wisconsin-Madison. Only right-handed subjects were used because of evidence that patterns of hemispheric activation for cognitive, and perhaps affective, functions may differ in left- and right-handers (for a review, see Bryden, 1982). Handedness was assessed by the Edinburgh Handedness Inventory (Oldfield, 1971). Due to equipment malfunctions or other technical problems, 5 subjects' EEG data were not usable for at least one of the two experimental sessions. This resulted in a final sample size of 85 used in the analyses reported below.

Procedure

Session 1. Subjects participated in two experimental sessions, approximately three weeks apart. All subjects were run individually. After electrodes were applied for the measurement of EEG, subjects were informed that all necessary instructions for the experimental procedure would be presented on a video monitor. After the experimenter left the room, the instructions informed subjects that: 1) there would be eight 1-min resting baselines; 2) four baselines would be conducted with eyes-open and four would be conducted with eyes-closed; and 3) during the resting baselines, they should try to minimize eyeblinks and movements, but not be so concerned about doing so that they were distracted. In accord with previous work in our laboratory (e.g, Tomarken et al., 1990), subjects were not given highly specific instructions concerning the resting baselines. They were told simply to try to be as "restful" as possible.

Two randomly assigned, counterbalanced orders were used for the eyes-open and eyes-closed trials of the resting baselines (O-C-C-O-C-O-O-C and C-O-O-C-O-C-C-O). Subjects heard one tone denoting the beginning of each 60-s baseline and two tones denoting the end of each baseline. There was a 3-min interval between the fourth and fifth baselines. A 45-s interval occurred between all other baselines. Following the eighth and final resting baseline, electrodes were removed and subjects completed a series of paper-and-pencil measures assessing individual differences in emotion and personality (see, e.g., Davidson, Abramson, Tomarken, & Wheeler, submitted; Tomarken et al., 1992).

Session 2. Subjects returned to the laboratory for the second experimental session approximately 3 weeks after Session 1. More specifically, the allowable interval between sessions was 17–25 days with the great majority of subjects returning exactly 21 days after the first session. The procedure for recording resting baselines was identical to that described in Session 1. Following the eight resting baselines, subjects were exposed to nine film clips preselected to elicit discrete emotions (see, e.g., Wheeler et al., in press).

EEG Recording and Quantification

EEG was recorded using a lycra stretchable cap (manufactured by Electro-Cap International, Inc., Eaton, OH) positioned on the subject's head using known anatomical landmarks. It has been shown that this procedure yields accurate electrode placements according to the 10-20 electrode system (Blom & Anneveldt, 1982). During Session 1, for the first several cohorts of subjects (n=43), EEG was recorded from the left and right midfrontal (F_3, F_4) and anterior temporal (T_3, T_4) regions. During recording, all four sites were referenced to vertex (C_Z). Two additional channels were recorded to derive an averaged-ears reference: C_Z-A_1 and C_Z-A_2 (A_1 = left earlobe and A_2 = right earlobe). For the remainder of the subjects (n=42), EEG was recorded from midfrontal and anterior temporal sites and the following 10 additional sites during Session 1: homologous lateral frontal (F_7, F_8), central (C_3, C_4), posterior temporal (T_5, T_6) and parietal (P_3, P_4) sites, and midline frontal (F_Z) and parietal (P_Z). During recording all these sites were referenced to vertex, and two additional C_Z-A_1 and C_Z-A_2 channels were included. In Session 2, for all subjects, recordings were made from all 16 sites noted above.

All electrode impedances were under 5000 ohms, and the impedances for homologous sites were within 500 ohms of each other. In both sessions, eye movements (EOG) were also recorded to facilitate artifact-scoring of EEG. EOG was recorded from the external canthus to the supra-orbit of one eye. The eye from which recordings were made was randomly determined for each subject. EEG was amplified with a Grass Model 12 Neurodata System using Model 12A5 pre-amplifiers (bandpass = 1 and 100 Hz; 60 Hz notch filter in) and passed through anti-aliasing low-pass filters (Rockland Model 424) set at 65 Hz and characterized by a roll-off of 24dB/octave. EEG was digitized at 200 Hz by a PDP 11/34A minicomputer. The EEG and EOG signals were visually scored and those portions of the data containing eye movements, muscle movements, or other sources of artifact were deleted. When artifact occurred on a given channel, data from all channels were removed.

The 25-μV and 50-μV 10 Hz sine waves were digitized on each channel to calibrate the digitized EEG. To assess the technical integrity of the recording system, additional calibration trials were run during which 4 Hz, 20 Hz, and 40 Hz 25-μV and 50-μV sine waves were digitized. These trials were run both immediately before and immediately after each experimental session. For 6 subjects, these calibration trials revealed slightly lower than expected A-to-D counts for the 40-Hz calibration trial of one session. For these subjects, A-to-D counts yielded by all other calibration trials were well within the normal range, with the exception of one subject, for whom one 20-Hz calibration trial yielded slightly lower than expected A-to-D counts. Although these deviations from expected values were slight, we decided to omit the high-frequency band (beta 2 = 20–30 Hz) data of these 6 subjects from analyses and to omit the beta 1 band (13–20 Hz) data of the subject with slightly deviant 20-Hz calibration values. The results and conclusions are unchanged if the data from these 6 subjects are omitted from the analyses of all frequency bands.

In addition to the original recording montage referenced to vertex, EEG was recomputed off-line to derive a computer-averaged ears reference. The computer-averaged reference is conceptually equivalent to the more traditional linked-ears reference but avoids the potential problem of attenuation of the magnitude of asymmetry due to physical linking of the ears (e.g., Davidson, 1988; Nunez, 1981).[1] To compute the computer-averaged ears reference, the C_Z-A_1 and C_Z-A_2 channels were averaged and added to the original vertex-referenced data. More specifically, to derive this reference, the following computations were made (in this example, F_3 serves as the site for which power is derived):

$$(F_3 - C_z) + [(C_Z - A1) + (C_Z - A_2)]/2 \quad (1)$$

$$= F_3 - C_z + C_Z - (A_1 + A_2)/2 \quad (2)$$

$$= F_3 - (A_1 + A_2)/2 \quad (3)$$

All artifact-free chunks that were 2.05 s in duration were extracted through a Hamming window, used to prevent spurious estimates of spectral power. Chunks were overlapped by 75% to counteract the differential weighing of data points attributable to the use of the Hamming window (for a review, see Dumermuth & Molinari, 1987). A Fast Fourier Transform (FFT) was then used to derive estimates of spectral power (in μV^2) in different 1-Hz frequency bins. These power values were then averaged across each of the artifact-free chunks of a given resting baseline trial. Finally, power values were converted to power density (μV^2/Hz) in each of five bands: delta (1–4 Hz), theta (4–7 Hz), alpha (8–13 Hz), beta 1 (13–20 Hz), and beta 2 (20–30 Hz). Power density was computed by summing power values across all the 1-Hz bins within a band and then dividing by the number of bins.

To normalize the data, we log-transformed all power density values (Davidson, Chapman, Chapman, &

---

[1] At the time that this study was begun, data were unavailable concerning the degree to which physical linking of the ears does in fact attenuate the magnitude of observed EEG asymmetry. Since that time, Senulis and Davidson (1989) have reported that physical linking of the ears does not appear to have any systematic effect on alpha power asymmetry. Recently, Andino et al. (1990) have reported the same finding.

Henriques, 1990; Gasser, Bacher, & Mocks, 1982). Then, for the purpose of analyses assessing the stability of anterior EEG asymmetry across Sessions 1 and 2, we computed weighted means across each of the eight baselines of a given session. Several steps were used in the computation of weighted means. First, for each baseline, we multiplied (i.e., weighted) the power density value for a given band (e.g., alpha) and site (e.g., F_3) by the number of artifact-free 2.05-s chunks of EEG available during that baseline. When a subject had fewer than 10 artifact-free chunks for a given baseline, that baseline was not included in the computation; that is, it received a weight of zero. In fact, such zero-weighting occurred fairly rarely, because baselines tended to have a large number of artifact-free chunks (6.84% of all baselines contained <10 chunks of artifact-free data; mean duration of artifact-free EEG = 43 s per baseline).[2]

In the next step, we summed the weighted power density values across each of the eight baselines of a given session, after which we divided by the total number of artifact-free chunks for that session. This process resulted in the generation of a weighted mean log power density value for a given session. In the final stage, measures of EEG asymmetry in the midfrontal and anterior temporal regions were derived for each combination of band (delta, theta, alpha, beta 1, and beta 2) and reference (C_Z and averaged ears). Asymmetry was computed as the difference between mean log power density in a right hemisphere lead and mean log power density in the homologous left hemisphere lead (i.e., log R minus log L power density).[3]

There were several reasons why we pooled over both eyes-open and eyes-closed baselines when computing the asymmetry values used in the primary analyses assessing stability. First, pooled values were used in the majority of our previous studies demonstrating relations between resting anterior asymmetry and emotion measures. Second, the correlations between eyes-open and eyes-closed asymmetry values were of sufficient magnitude to justify aggregation. We computed correlations between eyes-open and eyes-closed asymmetry for each combination of frequency band, reference, and site. The four correlations within each frequency band averaged as follows: delta, $\overline{X}=.74$, range=.65–.84; theta, $\overline{X}=.73$, range=.65–.80; alpha, $\overline{X}=.67$, range=.51–.79; beta 1, $\overline{X}=.62$, range=.47–.77; and beta 2, $\overline{X}=.64$, range=.56–.73. Third, in the great majority of cases, the test-retest stability of asymmetry measures pooled over eyes-open and eyes-closed baselines was either: 1) greater than the stability values for both eyes-open and eyes-closed asymmetry, or 2) greater than one of the two eyes-open/eyes-closed values and essentially equal to the other. In only one case (beta 1 band, midfrontal site, vertex reference) was the stability of the pooled measure notably lower than that of either the eyes-closed or eyes-open measure. For this reason, in addition to presenting the test-retest stability of beta 1 asymmetry pooled over eyes-open and eyes-closed baselines below (see Table 4), we present the separate stabilities of eyes-open and eyes-closed asymmetry in the beta 1 band (see Table 6). Because our recent findings focus on EEG asymmetry in the alpha band, we also present the separate eyes-open and eyes-closed stabilities of alpha asymmetry below.

Stability Analyses

We assessed the stability of power and asymmetry measures across sites, bands, and references in several ways. First, we computed matched-pair *t*-tests assessing the difference between Session 1 and Session 2 means. Second, we computed both Pearson correlations and intraclass correlations (e.g., Shrout & Fleiss, 1979; Strube, 1990) to estimate the test-retest stability of power and asymmetry measures. Because intraclass correlations may be unfamiliar to readers, several of their relevant features should be noted. First, there are several alternative models for the intraclass correlation (Shrout & Fleiss, 1979). In the present study, these alternatives differ in whether between-session effects are estimated and, if so, whether such effects are considered fixed or random. The model that we used estimated the between-session component of variance as a fixed effect (i.e., Shrout & Fleiss's formula numbered "3,1"). Subsidiary analyses revealed, however, that the magnitudes of the intraclass correlations reported were essentially unchanged if alternative models were used. This concordance across models is largely due to the relatively small between-session mean differences.

Second, as evidenced by the results presented below, in the majority of cases the intraclass *r*'s were essentially identical to the Pearson *r*'s. This concordance is due largely to the fact that the standard deviation of a given measure (e.g., frontal asymmetry) tended to remain relatively constant across sessions. It can be shown (see footnote 4) that when standard deviations are identical and the number of levels of the within-subjects factor equals two, fixed-effect intraclass correlations computed according to Shrout and Fleiss's model (3,1) and Pearson *r*'s are mathematically identical.[4]

---

[2] In addition to the zero-weighing criteria for individual baselines, we also imposed subject selection criteria. Specifically, we decided a priori to eliminate any subjects with fewer than 10 artifact-free chunks of EEG across the four eyes-open or four eyes-closed baselines of a given session. Due to the consistently large amount of artifact-free EEG, imposition of these criteria resulted in the elimination of no subjects.

[3] Although we have used the Log R minus Log L measure in all of our recent studies on individual differences in anterior asymmetry, a number of previous studies have used the following ratio measure of asymmetry: (R − L)/(R + L), where "R" and "L" denote power density in homologous right and left hemisphere leads. In the present study, as in previous studies (see Davidson, 1988), log difference and ratio scores were very highly correlated (e.g., *r*'s in the .90–.99 range). Consequently, the results yielded by the two measures were essentially identical.

[4] The intraclass *r* for the model used in the present study is equivalent to the ratio of the mean of the covariances between the levels of the within-subjects factor (i.e.,

In the present paper, we report both sets of correlations, for two reasons. First, in our opinion, intraclass *r*'s are more appropriate indices of stability, because they are more readily generalizable to contexts in which stability is assessed across multiple timepoints. Research currently in progress in our laboratories is addressing this latter question. On the other hand, we believe that Pearson *r*'s are more appropriate for statistical tests of the difference between stability correlations that we conducted and that are presented below. We tested for the difference between correlations using the Z_2* statistic (Dunn & Clark, 1969) for dependent correlations (for a review, see Steiger, 1980). The computation of Z_2* for tests of the difference between two correlations (r_{jk} and r_{hm}) requires the calculation of four additional correlations (r_{jh}, r_{jm}, r_{kh}, r_{km}). In certain cases, these latter four correlations involved pairs of variables with very different variances (e.g., a measure of power and a measure of asymmetry). Because these differing variances reflected differences in what might be considered the "natural" ranges or metrics of the measures and not problematic features of the data, and because intraclass correlations, relative to Pearson *r*'s, tend to be deflated markedly by large differences in variances, the use of intraclass correlations in the computation of Z_2* might have led to distorted results relative to those yielded by the use of Pearson *r*'s.

Finally, in addition to presenting intraclass correlations that assess the stability of EEG assessed at one point in time, we also present intraclass correlations estimating the stability of EEG averaged across two sessions (Shrout & Fleiss, 1979). These latter intraclass correlations (ICCs) are mathematically identical to estimates that would be derived from application of the Spearman-Brown prophecy formula to the one-session estimates. In tables and text, one-session stability estimates are denoted "ICC1" and two-session estimates are denoted "ICC2." For both sets of ICCs, 95% confidence intervals were computed (e.g., Shrout & Fleiss, 1979), and are also presented in the tables below.

Results

Test-Retest Stability Across Sites and Bands

Tables 1–5 present the test-retest stability data for each of the five frequency bands, respectively (delta, theta, alpha, beta 1, and beta 2). Below, we will highlight the general patterns of results in these tables by discussing the effects on stability measures of differences in EEG measures (power density vs. asymmetry), EEG bands, referencing schemes (vertex vs. averaged ears), and regions (midfrontal vs. anterior temporal).

Comparisons between power and asymmetry measures. Examination of the Pearson *r*'s and intraclass correlations in Tables 1–5 reveals a consistent disparity between the stability of log power density and the stability of EEG asymmetry. Consistent with prior findings (e.g., Gasser et al., 1982; Pollock et al., in press), absolute power measures demonstrated excellent stability, with correlations in the .8–.95 range consistently evidenced for the theta, alpha, and beta 1 bands. Somewhat lower, but still quite respectable, correlations were evidenced for the delta and beta 2 bands. Although the correlations for asymmetry measures were always statistically significant, and often rather impressive in magnitude (see also below), these values were consistently lower than those for absolute power. In certain cases, the discrepancy between the test-retest stability of power and asymmetry values was quite notable. In support of these observations were the results of Z_2* tests comparing the Pearson *r* stability correlations of power measures to those of their corresponding asymmetry measures. Of the 40 Z_2* tests conducted (5 bands, 8 tests per band), 36 yielded significant differences at the $p<.05$ level, with the majority yielding differences at $p<.001$.

The results of *t*-tests comparing the overall means for each session indicated a less notable difference between the stability of power and asymmetry than was indicated by the correlational analyses. Using a $p<.05$ criterion, both absolute power and asymmetry measures tended to be associated with nonsignificant shifts in mean values over time. Results for the delta band were one exception to this conclusion. In this case, three of the four asymmetry measures were associated with significant mean changes over time, whereas none of the absolute power measures were.

Because asymmetry measures are more relevant than power measures to our previous research and the overall goals of the present paper, we will focus on the results for the former in the sections below.

Comparisons among frequency bands. Concerning differences among frequency bands, across various combinations of site and reference, the stability correlations for alpha band asymmetry were consistently either the highest, or among the highest, relative to the asymmetry values of other frequency bands. In addition, the overall session means for alpha asymmetry were stable over time (see Table 3). Asymmetries in the delta and beta 1 bands tended to demonstrate the lowest stability. Z_2* tests comparing the Pearson *r* stability correlations among frequency bands revealed that: 1) averaged-ears midfrontal asymmetry and vertex-ref-

---

in the present case, sessions) and the mean of the variances of these levels (Winer, 1971). When the number of levels equals 2 and the standard deviations of the two levels (SD1 and SD2) are equal, this formula reduces to COV(1,2)/[(SD1)(SD2)], where COV(1,2) = the covariance between the two levels. This is a standard definitional formula for the Pearson *r*.

Table 1

Stability of log power density ($\mu V^2/Hz$) and asymmetry in the delta band (1–4Hz)

				Stability Correlations		
Reference/EEG Measure	Time 1 Mean (SD)	Time 2 Mean (SD)	Time 2 Mean −Time 1 Mean t	Pearson r	ICC1 (95% Conf. Int.)	ICC2 (95% Conf. Int.)
Midfrontal Region (N=85)						
Average Ears						
F_3 Power	1.57 (.36)	1.54 (.40)	<1	.71****	.71**** (.58–.80)	.83**** (.73–.89)
F_4 Power	1.59 (.35)	1.59 (.41)	<1	.69****	.68**** (.54–.77)	.81**** (.70–.87)
Asymmetry	.027 (.09)	.050 (.09)	2.09*	.39****	.40**** (.20–.56)	.57*** (.34–.72)
Vertex						
F_3 Power	.69 (.42)	.66 (.44)	<1	.79****	.79**** (.69–.86)	.88**** (.82–.92)
F_4 Power	.72 (.40)	.75 (.42)	<1	.69****	.69**** (.56–.79)	.82**** (.72–.88)
Asymmetry	.030 (.16)	.086 (.17)	2.94***	.42****	.42**** (.23–.58)	.59**** (.37–.73)
Anterior Temporal Region (N=85)						
Average Ears						
T_3 Power	.63 (.39)	.62 (.37)	<1	.77****	.77**** (.67–.84)	.87**** (.80–.92)
T_4 Power	.66 (.42)	.65 (.41)	<1	.80****	.80**** (.71–.87)	.88**** (.83–.93)
Asymmetry	.025 (.18)	.028 (.21)	<1	.63****	.63**** (.47–.74)	.77**** (.64–.85)
Vertex						
T_3 Power	1.40 (.38)	1.42 (.41)	<1	.76****	.76**** (.65–.84)	.86**** (.79–.91)
T_4 Power	1.37 (.39)	1.43 (.41)	1.77*	.74****	.74**** (.63–.82)	.85**** (.77–.90)
Asymmetry	−.034 (.14)	.007 (.13)	2.56**	.41****	.41**** (.22–.57)	.58**** (.35–.73)

Note.—All power values are log-transformed (natural log). Asymmetry = log right hemisphere power minus log left hemisphere power. Pearson r = Time 1/Time 2 Pearson correlation. ICC1 = intraclass correlation estimating the stability of measures assessed at one time-point. ICC2 = intraclass correlation estimating the stability of aggregate measures averaged across two time-points.

$^*p<.10$, $^{**}p<.05$, $^{***}p<.01$, $^{****}p<.001$.

Table 2

Stability of log power density ($\mu V^2/Hz$) and asymmetry in the theta band (4–7Hz)

				Stability Correlations		
Reference/EEG Measure	Time 1 Mean (SD)	Time 2 Mean (SD)	Time 2 Mean −Time 1 Mean t	Pearson r	ICC1 (95% Conf. Int.)	ICC2 (95% Conf. Int.)
Midfrontal Region (N=85)						
Average Ears						
F_3 Power	1.23 (.65)	1.24 (.69)	<1	.88**	.88** (.82–.92)	.94** (.90–.96)
F_4 Power	1.25 (.64)	1.26 (.66)	<1	.88**	.88** (.82–.92)	.94** (.90–.96)
Asymmetry	.019 (.09)	.019 (.12)	<1	.51**	.50** (.30–.63)	.67** (.46–.77)
Vertex						
F_3 Power	.38 (.67)	.43 (.71)	1.62*	.89**	.89** (.83–.93)	.94** (.91–.96)
F_4 Power	.39 (.65)	.46 (.68)	1.84*	.88**	.88** (.82–.92)	.94** (.90–.96)
Asymmetry	.015 (.16)	.022 (.17)	<1	.56**	.56** (.39–.69)	.74** (.56–.82)
Anterior Temporal Region (N=85)						
Average Ears						
T_3 Power	.10 (.71)	.11 (.69)	<1	.90**	.90** (.85–.93)	.95** (.92–.97)
T_4 Power	.09 (.73)	.09 (.72)	<1	.90**	.90** (.85–.93)	.95** (.92–.97)
Asymmetry	−.011 (.20)	−.023 (.21)	<1	.57**	.57** (.41–.70)	.75** (.58–.82)
Vertex						
T_3 Power	1.22 (.64)	1.25 (.65)	1.05	.88**	.88** (.82–.92)	.94** (.90–.96)
T_4 Power	1.19 (.63)	1.26 (.66)	1.77*	.88**	.88** (.82–.92)	.94** (.90–.96)
Asymmetry	−.024 (.14)	.002 (.13)	1.95*	.55**	.57** (.38–.68)	.71** (.55–.81)

Note.—All power values are log-transformed (natural log). Asymmetry = log right hemisphere power minus log left hemisphere power. Pearson r = Time 1/Time 2 Pearson correlation. ICC1 = intraclass correlation estimating the stability of measures assessed at one time-point. ICC2 = intraclass correlation estimating the stability of aggregate measures averaged across two time-points.

$^*p<.10$, $^{**}p<.001$.

erenced anterior temporal asymmetry in the alpha band were significantly more stable than their corresponding delta band asymmetry measures (p's $<$ .05 and .01, respectively); 2) midfrontal alpha asymmetry derived from both reference montages was more stable than midfrontal beta 1 asymmetry (averaged-ears $p<.01$; vertex $p<.05$); 3) averaged-ears anterior temporal asymmetry in the alpha band

Table 3

Stability of log power density ($\mu V^2/Hz$) and asymmetry in the alpha band (8–13Hz)

Reference/EEG Measure	Time 1 Mean (SD)	Time 2 Mean (SD)	Time 2 Mean −Time 1 Mean *t*	Stability Correlations		
				Pearson *r*	ICC1 (95% Conf. Int.)	ICC2 (95% Conf. Int.)
Midfrontal Region (N=85)						
Average Ears						
F_3 Power	.99 (.89)	.92 (.88)	1.77*	.92**	.92** (.88–.95)	.96** (.94–.97)
F_4 Power	1.02 (.88)	.96 (.87)	1.55	.91**	.91** (.86–.94)	.95** (.93–.97)
Asymmetry	.030 (.09)	.038 (.10)	<1	.66**	.66** (.52–.76)	.79** (.68–.87)
Vertex						
F_3 Power	.15 (1.03)	.14 (.99)	<1	.92**	.92** (.88–.95)	.96** (.94–.97)
F_4 Power	.17 (1.01)	.16 (.97)	<1	.92**	.92** (.88–.95)	.96** (.94–.97)
Asymmetry	.018 (.13)	.025 (.13)	<1	.53**	.53** (.36–.67)	.69** (.53–.80)
Anterior Temporal Region (N=85)						
Average Ears						
T_3 Power	.24 (1.01)	.19 (.99)	1.35	.94**	.94** (.91–.96)	.97** (.95–.98)
T_4 Power	.37 (1.02)	.28 (.96)	1.86*	.92**	.92** (.88–.95)	.96** (.93–.97)
Asymmetry	.125 (.20)	.094 (.21)	1.24	.72**	.72** (.60–.89)	.84** (.75–.89)
Vertex						
T_3 Power	1.23 (.91)	1.18 (.90)	1.19	.93**	.93** (.89–.95)	.96** (.94–.98)
T_4 Power	1.26 (.94)	1.22 (.90)	1.03	.92**	.92** (.88–.95)	.96** (.94–.97)
Asymmetry	.031 (.24)	.034 (.22)	<1	.71**	.71** (.58–.80)	.83** (.74–.89)

Note.—All power values are log-transformed (natural log). Asymmetry = log right hemisphere power minus log left hemisphere power. Pearson *r* = Time 1/Time 2 Pearson correlation. ICC1 = intraclass correlation estimating the stability of measures assessed at one time-point. ICC2 = intraclass correlation estimating the stability of aggregate measures averaged across two time-points.
$*p<.10$, $**p<.001$.

Table 4

Stability of log power density ($\mu V^2/Hz$) and asymmetry in the beta 1 band (13–20Hz)

Reference/EEG Measure	Time 1 Mean (SD)	Time 2 Mean (SD)	Time 2 Mean −Time 1 Mean *t*	Stability Correlations		
				Pearson *r*	ICC1 (95% Conf. Int.)	ICC2 (95% Conf. Int.)
Midfrontal Region (N=84)						
Average Ears						
F_3 Power	−1.09 (.80)	−1.09 (.83)	<1	.91**	.91** (.86–.94)	.95** (.93–.97)
F_4 Power	−1.05 (.79)	−1.04 (.83)	<1	.88**	.88** (.82–.92)	.94** (.90–.96)
Asymmetry	.035 (.12)	.044 (.17)	<1	.36*	.34* (.12–.50)	.51** (.21–.67)
Vertex						
F_3 Power	−2.21 (1.05)	−2.16 (1.06)	1.15	.92**	.92** (.88–.95)	.96** (.91–.97)
F_4 Power	−2.13 (1.03)	−2.06 (1.02)	1.15	.89**	.89** (.84–.93)	.94** (.91–.96)
Asymmetry	.087 (.24)	.094 (.28)	<1	.28*	.28* (.06–.46)	.44** (.13–.63)
Anterior Temporal Region (N=84)						
Average Ears						
T_3 Power	−1.71 (1.08)	−1.81 (1.04)	1.64	.86**	.86** (.79–.91)	.92** (.88–.95)
T_4 Power	−1.67 (1.10)	−1.75 (.97)	1.29	.87**	.86** (.79–.91)	.92** (.88–.95)
Asymmetry	.037 (.47)	.060 (.49)	<1	.48**	.48** (.30–.63)	.65** (.46–.77)
Vertex						
T_3 Power	−.80 (.84)	−.83 (.85)	<1	.88**	.88** (.82–.92)	.94** (.90–.96)
T_4 Power	−.77 (.83)	−.81 (.78)	<1	.87**	.87** (.89–.95)	.93** (.89–.95)
Asymmetry	.024 (.35)	.027 (.31)	<1	.61**	.60** (.45–.73)	.75** (.62–.84)

Note.—All power values are log-transformed (natural log). Asymmetry = log right hemisphere power minus log left hemisphere power. Pearson *r* = Time 1/Time 2 Pearson correlation. ICC1 = intraclass correlation estimating the stability of measures assessed at one time-point. ICC2 = intraclass correlation estimating the stability of aggregate measures averaged across two time-points.
$*p<.01$, $**p<.001$.

was more stable than averaged-ears anterior temporal asymmetry in the beta 1 band ($p<.01$); and 4) vertex-referenced frontal asymmetry in the theta band was more stable than corresponding measures of delta and beta 1 power (p's$<.05$). It should be added, however, that noteworthy improvements in the stability of delta and beta 1 asymmetry are afforded by aggregation across two sessions, as in-

Table 5

Stability of log power density ($\mu V^2/Hz$) and asymmetry in the beta 2 band (20–30Hz)

				Stability Correlations		
Reference/EEG Measure	Time 1 Mean (SD)	Time 2 Mean (SD)	Time 2 Mean −Time 1 Mean *t*	Pearson *r*	ICC1 (95% Conf. Int.)	ICC2 (95% Conf. Int.)
			Midfrontal Region (N=79)			
Average Ears						
F_3 Power	−2.94 (.88)	−2.94 (.96)	<1	.91***	.91*** (.86–.94)	.95*** (.92–.97)
F_4 Power	−2.86 (.87)	−2.88 (.92)	<1	.90***	.90*** (.85–.93)	.95*** (.92–.97)
Asymmetry	.083 (.25)	.056 (.35)	<1	.52***	.49*** (.28–.62)	.66*** (.44–.76)
Vertex						
F_3 Power	−3.79 (1.27)	−3.67 (1.28)	1.61	.88***	.88*** (.82–.92)	.94*** (.90–.96)
F_4 Power	−3.66 (1.25)	−3.60 (1.26)	<1	.85***	.85*** (.78–.90)	.92*** (.88–.95)
Asymmetry	.126 (.41)	.069 (.54)	1.02	.49***	.47*** (.27–.61)	.64*** (.42–.76)
			Anterior Temporal Region (N=79)			
Average Ears						
T_3 Power	−3.72 (1.60)	−3.95 (1.47)	1.80*	.73***	.73*** (.61–.81)	.84*** (.76–.90)
T_4 Power	−3.62 (1.36)	−3.85 (1.33)	2.17**	.77***	.77*** (.67–.84)	.87*** (.80–.92)
Asymmetry	.097 (1.14)	.104 (1.06)	<1	.60***	.60*** (.44–.72)	.75*** (.61–.84)
Vertex						
T_3 Power	−2.32 (1.10)	−2.46 (1.10)	1.73*	.79***	.79*** (.69–.86)	.88*** (.82–.97)
T_4 Power	−2.37 (1.06)	−2.44 (1.01)	<1	.79***	.79*** (.69–.86)	.88*** (.82–.92)
Asymmetry	−.051 (.71)	.021 (.62)	1.18	.66***	.65*** (.50–.75)	.79*** (.67–.86)

Note.—All power values are log-transformed (natural log). Asymmetry = log right hemisphere power minus log left hemisphere power. Pearson *r* = Time 1/Time 2 Pearson correlation. ICC1 = intraclass correlation estimating the stability of measures assessed at one time-point. ICC2 = intraclass correlation estimating the stability of aggregate measures averaged across two time-points.

$^*p<.10$, $^{**}p<.05$, $^{***}p<.001$.

dicated by the Intraclass Correlations 2 presented in Tables 1 and 4.

Because our previous findings on the affective and other correlates of individual differences in anterior asymmetry focused on alpha power, assessment of the stability of alpha asymmetry was a central concern of the present study. For this reason, in Figures 1 and 2, we present scatter plots depicting the across-session test-retest stability of averaged-ears referenced midfrontal and anterior temporal alpha asymmetry, respectively. Averaged-ears referenced values are shown in these figures because this montage yielded the best stability values overall and because it has been used in the majority of our previous studies with adult subjects that demonstrate relations between resting anterior asymmetry and emotion measures. Considered together, Table 3 and Figures 1 and 2 indicate that resting alpha asymmetry has a strong individual differences component.

Comparison between regions. Across references and frequency bands, asymmetry in the anterior temporal band tended to be either more stable than, or as stable as, midfrontal asymmetry. In the case of averaged-ears referenced asymmetry in the delta band, and vertex-referenced asymmetry in the alpha and beta 1 bands, the disparity between anterior temporal and midfrontal asymmetry was notable and statistically significant (Z_2^* *p*'s<.05).

Comparison between reference montages. Overall, no consistent pattern was evidenced by comparisons of the relative stability of averaged-ears and vertex-referenced EEG asymmetry. In the majority of cases, stability values were comparable for the two referencing schemes. The only significant difference yielded by Z_2^* tests was the greater stability of averaged-ears, relative to vertex-referenced, asymmetry in the delta band for the anterior temporal site ($p=.05$) (see Table 1).

Comparisons between eyes-open and eyes-closed baselines. Table 6 presents the separate stability correlations for eyes-open and eyes-closed asymmetry in the alpha and beta 1 bands. The test-retest *r*'s for eyes-open and eyes-closed alpha asymmetry measures were generally comparable, with the exception of midfrontal averaged-ears asymmetry. In this case, eyes-closed asymmetry was significantly more stable than eyes-open asymmetry (Z_2^* $p<.01$). Interestingly, in the alpha band, the stability values of the four midfrontal eyes-closed baselines, and of the four eyes-open and eyes-closed baselines in the anterior temporal region, were comparable to the values evidenced for the overall asymmetry measures pooled across all eight baselines (compare Table 6 to Table 3).

Greater stability of eyes-closed relative to eyes-open baselines was more evident in the beta 1 band. However, only the vertex-reference midfrontal

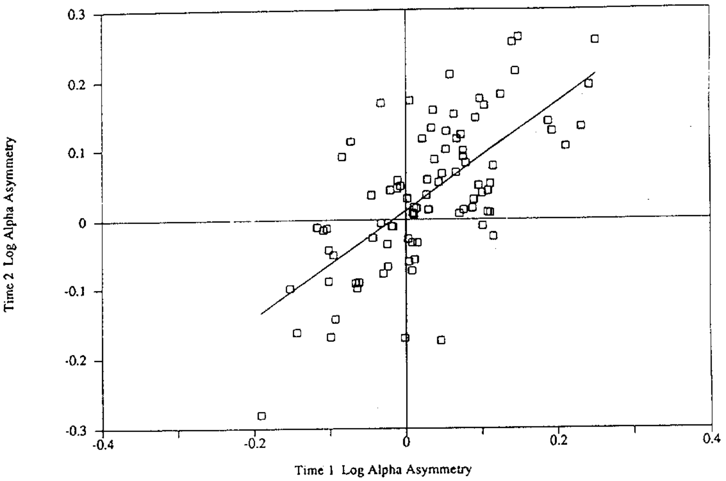

Figure 1. Scatterplot of the test-retest stability of averaged-ears referenced midfrontal asymmetry in the alpha band. Each square denotes one subject (N=85).

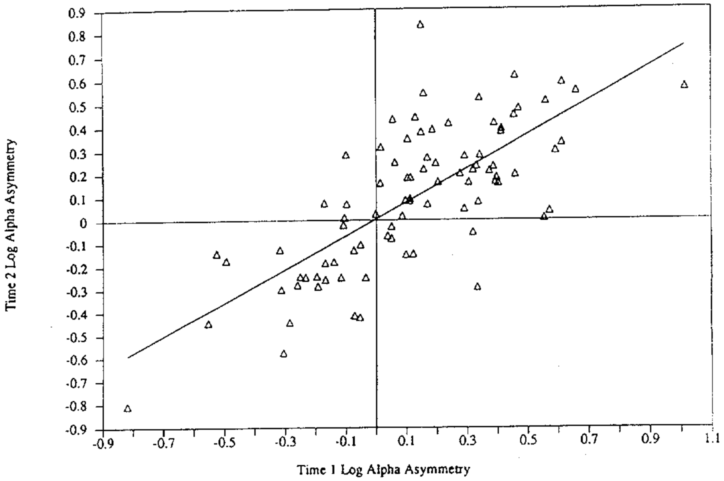

Figure 2. Scatterplot of the test-retest stability of averaged-ears referenced anterior temporal asymmetry in the alpha band. Each triangle denotes one subject (N=85).

comparison was statistically significant ($p<.01$). In other bands, eyes-open and eyes-closed stability values were consistently comparable, with the exception of anterior temporal averaged-ears asymmetry in the beta 2 band. In this case, eyes-open asymmetry ($r=.61$) was more stable than eyes-closed asymmetry ($r=.39$) ($p<.05$).

Additional Analyses of Alpha Asymmetry

Effects of degree of aggregation. To assess more comprehensively the psychometric properties of resting asymmetry in the alpha band, three additional sets of analyses were conducted. The first of these was based on the extensive evidence from a variety of contexts supporting the basic psychometric principle that heightened aggregation is associated with greater reliability and/or stability (e.g, Epstein, 1979, 1980; for a review, see Rushton, Brainerd, & Pressley, 1983). The greater stability of Intraclass Correlations 2, relative to Intraclass Correlations 1, in Tables 1–5 serves as one concrete demonstration of this principle. We expected similar improvements in test-retest stability as a result of increased aggregation across baselines. To test this latter prediction, we computed the stability of midfrontal and anterior temporal asymmetry pooled over the first two, the first four, the first six, and all eight baselines of a given session. In each

Table 6

Stability of asymmetry in the alpha (8–13 Hz) and beta 1 (13–20 Hz) bands for eyes-open and eyes-closed baselines

	Eyes-Open		Eyes-Closed	
Region/Reference	**Pearson *r***	**ICC1 (95% Conf. Int.)**	**Pearson *r***	**ICC1 (95% Conf. Int.)**
	Alpha Band (N=85)			
Midfrontal				
Average Ears	.45**	.45** (.26–.60)	.68**	.68**[a] (.54–.78)
Vertex	.44**	.42** (.21–.57)	.48**	.48** (.30–.63)
Anterior Temporal				
Average Ears	.67**	.67** (.53–.77)	.69**	.69** (.56–.79)
Vertex	.64**	.63** (.47–.74)	.71**	.71** (.58–.80)
	Beta 1 Band (N=84)			
Midfrontal				
Average Ears	.28*	.27* (.07–.46)	.43**	.42** (.22–.58)
Vertex	.08	.07 (.00–.28)	.51**	.48**[b] (.29–.62)
Anterior Temporal				
Average Ears	.33**	.33** (.13–.51)	.46**	.46** (.27–.61)
Vertex	.48**	.48** (.30–.63)	.59**	.58** (.42–.70)

Note.—Asymmetry = log right hemisphere power minus log left hemisphere power. Pearson *r* = Time 1/Time 2 Pearson correlation. ICC1 = intraclass correlation estimating the test-retest stability of measures assessed at one time-point.

[a] Eyes-open and eyes-closed *r*'s differ at $p<.05$.

[b] Eyes-open and eyes-closed *r*'s differ at $p<.01$.

*$p<.01$, **$p<.001$.

case, given the nature of the baseline orders used, half of the baselines in each index were always eyes-open and half were eyes-closed. To ensure that any differences between time-points would not be due to differing groups of subjects included in computations, we restricted the analyses to those subjects with artifact-free EEG that met the minimum chunk criteria noted above for every index computed. Thus, for example, only those subjects were included who had at least 10 chunks of data for the first eyes-open and eyes-closed baselines. Using this criterion, 57 subjects were included in the midfrontal analyses and 58 subjects were included in the anterior temporal analyses.

Figure 3 shows the effects of aggregation on Intraclass Correlation 1 assessing test-retest stability of both averaged-ears referenced and vertex-referenced EEG asymmetry.[5] This figure reveals that, for averaged-ears referenced EEG asymmetry in both regions, and vertex-referenced EEG asymmetry in the anterior temporal region, increases in aggregation were associated with increased test-retest stability up to the point at which six baselines were averaged. In contrast, the stability of vertex-referenced midfrontal asymmetry did not vary appreciably with degree of aggregation. Consistent with these observations, Z_2^* tests revealed that the stabilities of the first six baselines and of all eight baselines were significantly greater than the stabilities of the first two baselines for the two averaged-ears asymmetry measures and for vertex-referenced anterior temporal asymmetry (averaged-ears midfrontal p's$<.05$; all other p's$<.005$). Additionally, four baselines were more stable than two baselines

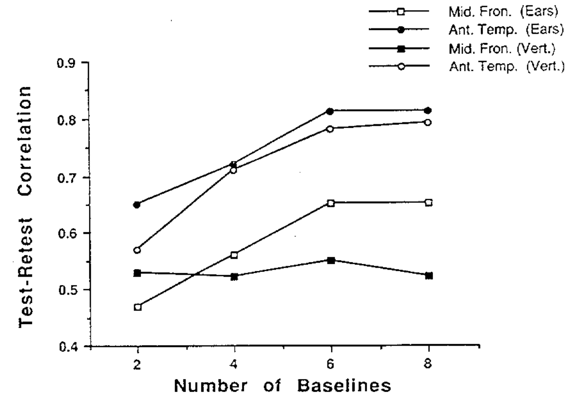

Figure 3. Effects of degree of aggregation across baselines on the intraclass correlations assessing the test-retest stability of midfrontal (n=57) and anterior temporal (n=58) EEG asymmetry in the alpha band. Both averaged-ears and vertex-referenced asymmetry values are shown.

---

[5] The smaller sample sizes for these analyses relative to the overall stability analyses reported above account for the slight differences between the two sets of analyses in the test-retest stability correlations computed across all eight baselines.

for vertex-referenced anterior temporal asymmetry ($p<.01$). At six baselines, however, stability values reached an asymptote, with no evident differences between EEG asymmetry averaged across six and eight baselines.

Internal consistency of alpha asymmetry. As noted above, another desirable psychometric feature of any measure of a construct is adequate internal consistency reliability. To assess the internal consistency of measures of resting anterior asymmetry in the alpha band, we computed coefficient alphas (Cronbach, 1951) across the asymmetry values for each of the eight baselines of a given session. In addition, we computed coefficient alphas on baseline means averaged over Sessions 1 and 2. Two different sets of analyses were conducted using slightly different criteria for selection of subjects. In the first set, we included all subjects who had any artifact-free EEG for all eight baselines of a given session. Because complete data for all baselines was required for the computation of coefficient alpha, we did not assign a weight of zero to baselines with fewer than 10 chunks of usable EEG, as we had in the stability computations. Table 7 shows the values of coefficient alpha when subjects with fewer than 10 chunks of artifact-free EEG for a given baseline were included in computations. Additionally shown in this table are the average correlations among the baselines used to compute each coefficient alpha. These correlations are important because the two primary factors influencing the magnitude of coefficient alpha are the average correlation among items and the total number of items (e.g., Nunnally, 1978).

Table 7

Internal consistency reliability and average intercorrelations of alpha asymmetry measures across baselines (<10 chunks of EEG included)

	Coefficient Alpha		
Reference/ Reliability Measure	**Time 1**	**Time 2**	**Time 1/ Time 2 Mean**
Midfrontal Region (N=85)			
Average Ears			
Coef. Alpha	.83	.88	.90
Average *r*	.37	.47	.53
Vertex			
Coef. Alpha	.81	.86	.89
Average *r*	.35	.44	.51
Anterior Temporal Region (N=85)			
Average Ears			
Coef. Alpha	.90	.91	.94
Average *r*	.55	.56	.67
Vertex			
Coef. Alpha	.92	.89	.94
Average *r*	.59	.50	.65

Note.—Asymmetry = log right hemisphere power minus log left hemisphere power. Eight 60-s baselines were recorded in each session.

Assuming a minimally acceptable coefficient alpha in the .7–.75 range (Kraemer, 1981), all coefficient alphas shown in Table 7 were acceptable and most were excellent. The magnitude of the values observed for individual sessions was quite notable given that only eight baselines were assessed. This is analogous to computing coefficient alphas on an eight-item scale. The high levels of internal consistency observed were due largely to the high intercorrelations among individual baselines (see Table 7). These correlations were notably larger than those typically observed among items of a personality scale (Nunnally, 1978).[6]

We also computed coefficient alphas using a second set of selection criteria. As noted above, in the test-retest stability analyses, baselines with fewer than 10 chunks of artifact-free EEG were given a weight of zero. Thus, for some subjects, fewer than eight baselines were included in the computation of mean asymmetry for a given session. Because the number of items included in the aggregate index can be a major determinant of the magnitude of coefficient alpha, the use of a zero-weighting procedure raises the question of the internal consistency of resting EEG asymmetry when fewer than eight baselines are included. Unfortunately, because different baselines received a weight of zero for different subjects, it was impossible to estimate directly the internal consistency of measures of asymmetry aggregated over fewer than eight baselines. We did, however, estimate it indirectly by: 1) computing the average intercorrelations among baselines and coefficient alphas for that subgroup of subjects with at least 10 chunks of usable EEG for all eight baselines, and 2) using the Spearman-Brown prophecy formula to estimate the internal consistency of fewer numbers of baselines. These estimates were based on the average intercorrelations yielded in Step 1 (e.g., Nunnally, 1978).

Table 8 shows the estimates of coefficient alpha generated by this procedure for five to seven baselines and the coefficient alphas directly estimated for all eight baselines. As this table indicates, for both sets of sites and references, the estimated reliability coefficients remain high and well above minimal criteria of acceptability even when as few as five baselines are included in a summary index of asymmetry.

---

[6] Supplementary repeated measures ANOVAs revealed no significant changes in asymmetry across baselines for either experimental session.

Table 8

Internal consistency reliability and average intercorrelations of alpha asymmetry measures across baselines (<10 chunks of EEG excluded)

	Coefficient Alpha		
Reference/ Reliability Measure	**Time 1**	**Time 2**	**Time 1/ Time 2 Mean**
Midfrontal Region			
Average Ears			
Coef. Alpha$_8$	.87	.89	.94
Coef. Alpha$_7$	.85	.88	.93
Coef. Alpha$_6$	.83	.86	.92
Coef. Alpha$_5$	.80	.84	.90
Average r	.45	.51	.64
N	57	60	44
Vertex			
Coef. Alpha$_8$	.85	.89	.92
Coef. Alpha$_7$	.83	.88	.91
Coef. Alpha$_6$	.81	.86	.89
Coef. Alpha$_5$	.78	.83	.87
Average r	.41	.50	.58
N	56	60	44
Anterior Temporal Region			
Average Ears			
Coef. Alpha$_8$	.94	.93	.94
Coef. Alpha$_7$	.93	.92	.93
Coef. Alpha$_6$	.92	.90	.92
Coef. Alpha$_5$	.91	.89	.89
Average r	.67	.61	.67
N	57	60	43
Vertex			
Coef. Alpha$_8$	.92	.90	.94
Coef. Alpha$_7$	.91	.89	.93
Coef. Alpha$_6$	.90	.87	.92
Coef. Alpha$_5$	.88	.84	.89
Average r	.59	.52	.67
N	56	60	45

Note.—Asymmetry = log right hemisphere power minus log left hemisphere power. Eight 60-s baselines were recorded in each session. Alpha$_8$ = coefficient alphas computed across all eight baselines of a session. Alpha$_7$ = estimated coefficient alphas across seven baselines. Alpha$_6$ = estimated coefficient alphas across six baselines. Alpha$_5$ = estimated coefficient alphas across five baselines. The Alpha$_7$, Alpha$_6$ and Alpha$_5$ estimates were computed using the Spearman-Brown prophecy formula.

Comparisons of anterior and posterior alpha asymmetry. As noted above, for a subgroup of subjects (n=42), EEG was recorded in both anterior and more posterior sites in the two experimental sessions. Table 9 displays the test-retest stability correlations for measures of alpha asymmetry derived using the averaged-ears reference in the central (C_3/C_4), posterior temporal (T_5/T_6), and parietal (P_3/P_4) regions. In addition, this table displays the Pearson correlations between measures of anterior asymmetry and posterior asymmetry. As this table indicates, the stability of averaged-ears alpha asymmetry in more posterior sites is high, and comparable in magnitude to the stability values for alpha asymmetry in the midfrontal and anterior temporal regions shown in Table 3. Table 9 also shows that although anterior temporal asymmetry is at least moderately correlated with all three measures of asymmetry in more posterior sites, midfrontal asymmetry is moderately correlated with central asymmetry but essentially uncorrelated with posterior temporal and parietal asymmetry. This latter observation is consistent with our previous findings concerning the affective correlates of anterior and posterior asymmetry in normal subjects. This evidence indicates that frontal asymmetry is strongly related to positive and negative affect but that posterior asymmetry (i.e., parietal) generally fails to predict affective valence (for a review, see Davidson & Tomarken, 1989).[7]

Table 9

Alpha asymmetry in more posterior sites: Stability and relation with anterior asymmetry (averaged ears reference)

	Stability			**Pearson r's with Anterior Asymmetry**	
Site	**Pearson r**	**ICC1 (95% Conf. Int.)**	**ICC2 (95% Conf. Int.)**	**Midfrontal**	**Anterior Temporal**
Central (C_3/C_4)	.77***	.77*** (.67–.84)	.87*** (.80–.92)	.32*	.64***
Posterior Temporal (T_5/T_6)	.66***	.67*** (.53–.77)	.80*** (.70–.87)	.00	.40**
Parietal (P_3/P_4)	.73***	.73*** (.61–.82)	.84*** (.76–.90)	.12	.54***

Note.—N=42. Pearson r = Time 1/Time 2 Pearson correlation. ICC1 = intraclass correlation estimating the test-retest stability of measures assessed at one time-point. ICC2 = intraclass correlation estimating the test-retest stability of aggregate measures averaged across two time-points. Pearson r's between anterior and posterior sites were computed using means averaged across time-points.

$^*p<.05$, $^{**}p<.01$, $^{***}p<.001$.

---

[7] When we have compared depressives, or individuals with a history of depression, and normals, opposite relations between anterior asymmetry and posterior asymmetry have been found. That is, compared to non-depressives, depressives have a pattern of relative right hemisphere activation in anterior sites and a pattern of relative left hemisphere activation in posterior sites (e.g., Davidson, Schaffer, & Saron, 1985; Henriques & Davidson, 1990).

Discussion

Below, we will briefly summarize the major findings concerning the stability of EEG power and EEG asymmetry across frequency bands, regions, and reference montages. Then, we will focus on the major issue addressed in the present study, the psychometric properties of resting anterior EEG asymmetry in the alpha band.

Summary of Findings Across Frequency Bands

Overall, the stability analyses conducted across frequency bands, regions, and reference montages suggest several conclusions. First, these results indicate that the psychometric properties of measures of EEG power and EEG asymmetry are by no means redundant. The stability correlations for absolute power measures were consistently higher than the correlations for asymmetry measures. In addition, in the delta band, asymmetry, but not power, measures were susceptible to mean shifts over time.

Although measures of EEG asymmetry tended to be less stable over time than measures of power density, in all cases test-retest correlations for asymmetry measures pooled over eyes-open and eyes-closed baselines were statistically significant. Often these correlations were of sufficient magnitude to indicate a strong individual difference component in EEG asymmetry. However, the results of the present study indicate that the stability of asymmetry may be conditional on various factors. Perhaps the major factor is the particular frequency band assessed. In the present study, the stability of alpha asymmetry tended to be higher than, or as high as, measures of asymmetry in other frequency bands. On some comparisons, the stability of alpha asymmetry was significantly greater than the stability of measures of asymmetry in the delta and beta 1 bands. It should be added, however, that, as indicated by the Intraclass Correlations 2 shown in Tables 1–5, the stability of even delta and beta 1 asymmetry measures can be improved by aggregating measures across two recording sessions.

One other factor that sometimes moderated the degree of stability observed was the region assessed. In several instances, anterior temporal asymmetry was significantly more stable over time than midfrontal asymmetry. In contrast, the stability correlations for averaged-ears referenced and vertex-referenced EEG asymmetry were generally comparable, with only one significant difference between these two montages observed (anterior temporal asymmetry in the delta band).

Psychometric Properties of Resting Alpha Asymmetry

Based on our recent findings indicating that resting anterior EEG asymmetry in the alpha band is a measure that assesses affective predispositions, the major goal of the present study was to assess the stability and other psychometric properties of resting alpha asymmetry. We assessed the psychometric properties of resting alpha asymmetry using criteria that are usually invoked for paper-and-pencil personality measures. However, such criteria are clearly also relevant to psychophysiological measures of individual differences (Strube, 1990).

Overall, the present results indicated that the psychometric features of resting alpha asymmetry justify its conceptualization, and use, as a measure of individual differences. First, resting anterior asymmetry in both midfrontal and anterior temporal sites demonstrated excellent internal consistency reliability. In the present study, only a relatively small number of baselines (eight) was necessary to generate high coefficient alphas in the .8–.95 range. In addition, high internal consistency estimates were observed even when fewer than eight baselines were included in computations. These findings were largely due to the high intercorrelations among the 60-s resting baselines. In turn, one likely reason for these high intercorrelations is the fact that asymmetry scores for specific baselines were aggregated across all the artifact-free chunks of that baseline (see **Method** section).

Adequate internal consistency reliability could be considered a desirable feature of almost *any* measure of a construct, irrespective of whether the latter denotes stable individual differences (e.g., a "trait") or more transient states. A second psychometric property, which is more uniquely relevant to an individual difference measure, is stability over time. On the whole, our test-retest stability findings also indicated that resting anterior alpha asymmetry can be considered a measure of individual differences. First, across both midfrontal and anterior temporal sites, there were no significant mean shifts in resting alpha asymmetry over time. Second, the Intraclass Correlations 1 and Pearson *r* stability correlations indicated that resting anterior asymmetry has a strong individual difference component. Across both the vertex- and averaged-ears referenced montages, the Time 1/Time 2 correlations for anterior temporal asymmetry were slightly greater than .70. For the midfrontal site, stability values for the averaged-ears montage approximated these values (intraclass correlation = .66), although vertex-referenced alpha asymmetry in the midfrontal site was associated with somewhat lower test-retest stability (intraclass correlation = .53).

Several comments concerning the test-retest stability findings for resting alpha asymmetry are in order. First, analyses of the relation between degree of aggregation and stability suggested that six resting baselines can yield test-retest correlations that are, for all practical purposes, equivalent to those yielded by eight baselines. However, our findings suggest that stability will be underestimated when fewer than six baselines are used. Second, it might be argued that although intraclass correlation values in the .65–.75 range indicate *adequate* stability according to criteria that have been proposed for an individual difference measure (e.g., Kraemer, 1981), these stability values are not *optimal* according to criteria that might be invoked for a personality measure of a given trait. The fact that a relatively short time interval separated the two experimental sessions (three weeks) could also be cited as evidence that the stability correlations observed here are adequate but not optimal.

We suspect that one reason for our failure to find stability values higher than the .65–.75 range is the fact that resting anterior EEG asymmetry is susceptible to influences *other than* individual difference factors alone. For example, there is a wealth of prior evidence indicating that changes in anterior asymmetry can be induced by exposure to positive or negative emotion elicitors (for a review, see Davidson & Tomarken, 1989). In addition, it is likely that the stability of anterior asymmetry is influenced by other factors that have yet to be identified. Given these considerations, it may not be particularly surprising that correlations higher than the .65–.75 range were not found.

The notion that resting EEG asymmetry may reflect the joint contribution of both stable individual differences and more situational state-like factors is consistent with conclusions previously reached by Levy (1983) who has assessed asymmetric hemispheric activation using behavioral methods. This reasoning would also suggest that resting EEG asymmetry may well be most analogous to measures of personality or psychopathology that are known to reflect both variations in concurrent state and more stable individual differences (Tomarken et al., in press). For example, it is well known that the Beck Depression Inventory (BDI; Beck, Ward, Mendelson, Mock, & Erbaugh, 1961) is sensitive to both long-term depressive affect and more transient mood states (Depue & Monroe, 1978; Sacco, 1981).

One question raised by the argument that resting asymmetry is affected by both individual difference factors and more transient influences is that of the optimal methodological strategy for measurement of asymmetry and selection of subjects in future studies. Several alternative approaches are possible. First, it may well be that, in many cases, resting EEG asymmetry measured on one or two occasions is sufficiently stable to serve as a valid indicator of individual differences in anterior asymmetry for the sample as a whole. The high Intraclass Correlations 2 shown in Table 3 indicate that measures of anterior asymmetry aggregated over two occasions may provide particularly stable estimates of individual differences in resting asymmetry. Consistent with this reasoning, in several of our recent studies, we have found that resting asymmetry measured on one (e.g., Davidson & Fox, 1989; Tomarken et al., 1990) or two (e.g., Tomarken, Davidson, & Wheeler, submitted) occasions significantly predicted affective reactivity or individual differences in affective traits.

In specific cases, better prediction of affective variables may occur when alternative methodological approaches are used. For instance, in several of our recent studies we have found stronger relations between anterior asymmetry and emotion measures for those subjects who manifest particularly stable patterns of asymmetry over time, or for those subjects who demonstrate a combination of stable and extreme asymmetry (e.g., asymmetry scores in the top quartiles of the distribution on each of two occasions; e.g., Davidson et al., submitted; Tomarken et al., 1992; Wheeler et al., in press). These findings suggest that, in certain instances, stability of asymmetry may serve as a variable that moderates the relation between degree of asymmetry and emotion (for more extensive discussion of this issue, see Tomarken et al., 1992). Research currently in progress in our laboratories is testing the validity of this hypothesis.

We are also currently assessing the effects of alternative reference montages on the stability of anterior asymmetry. In recent years, several researchers have recommended source density analysis of electrophysiological measures using the Laplace transform as a way to increase the spatial resolution of recording and to avoid other problems associated with the use of active or potentially active reference sites (e.g., Hjorth, 1975; MacKay, 1984; Nunez, 1981). Unfortunately, the relatively limited sampling of sites in the present investigation (especially during Session 1) precluded the use of a Laplacean derivation in the present study.

Anatomical Contributions to the Stability of Asymmetry

One final issue deserving consideration is that of the underlying physiological and anatomical substrates of EEG asymmetry and their relation to the measurement of asymmetry and estimates of its stability. Previously, we have interpreted resting anterior EEG asymmetry as a measure of individual differences in regional brain activation. Consistent with proposals made by Levy (1983; Levy, Heller, Banich, & Burton, 1983), we have speculated that such individual differences in activation are superimposed on a relatively invariant pattern of hemispheric specialization. We have further speculated that such activation differences may account for individual differences in affective and related traits that are observed despite such invariance (for more extensive discussion, see Davidson & Tomarken, 1989).

However, it could be argued that resting EEG asymmetry reflects the contribution of other factors. For example, there is evidence that asymmetrical skull thickness or other cranial asymmetries can predict electrophysiological asymmetries (Coppola, Karson, Daniel, & Myslobodsky, 1987; Leissner, Lindholm, & Petersen, 1970; Myslobodsky, Coppola, et al., 1989). In addition, Coppola, Myslobodsky, and their associates have recently found that neuro-anatomical brain asymmetries can predict electrophysiological asymmetries (Myslobodsky, Bar-Ziv, van Praag, & Glicksohn, 1989; Myslobodsky, Coppola, et al., 1989). Because skull thickness and anatomical asymmetries are obviously stable over time, one could argue that these factors may at least partially account for the high test-retest stability observed for measures of anterior EEG asymmetry in the present study.

Although future studies are necessary to definitively assess the relation between cranial and/or anatomical brain asymmetries and EEG asymmetry, two points relevant to this issue can be made at the present time. First, our findings indicating linkages between individual differences in emotion and resting anterior EEG asymmetry directly parallel previous findings indicating relations between experimentally induced positive and negative affective states and EEG asymmetry. Thus, for example, just as stable individual differences in negative affect have been associated with resting right anterior activation (e.g., Tomarken et al., 1992), experimentally induced negative affective states have been associated with increased relative right anterior activation (e.g., Davidson, Ekman, Saron, Senulis, & Friesen, 1990). These latter findings indicating linkages between anterior asymmetry and affective states are based on within-subjects comparisons and designs. Thus, it is highly likely that these results are attributable to genuine activation asymmetries and not asymmetrical skull thickness or neuro-anatomical asymmetries. In turn, the parallels between the two sets of asymmetry findings would suggest that activation asymmetries may similarly be the primary factor that underlies the relation between individual differences in resting asymmetry and emotion.

Second, in a recent small study, we have directly examined the relation between EEG asymmetry and cranial or neuro-anatomical asymmetries (Davidson, Pardington, Wheeler, Doss, & Tomarken, in preparation). Using magnetic resonance imaging (MRI), we compared brain asymmetries in two small groups of subjects run in the present cohort (total $N=9$): those who demonstrated stable and extreme right frontal activation and those who demonstrated stable and extreme left frontal activation. Despite the fact that these two groups represented opposite extremes of the distribution of EEG asymmetry scores, they failed to differ on all measures of skull or neuro-anatomical asymmetries computed. Indeed, no trends were even evident. Although this finding clearly requires replication and extension using a larger sample size, it suggests that cranial or anatomical asymmetries do not account significantly for the effects of individual differences in EEG asymmetry observed in the present and previous studies.[8]

Summary and Conclusions

In summary, the present findings indicate that the psychometric features of resting alpha asymmetry in anterior scalp regions generally support its conceptualization as a measure of individual differences. Resting anterior asymmetry in the alpha band has excellent internal consistency and adequate test-retest stability. Future research is necessary to compare the effects of alternative approaches to the measurement and quantification of anterior asymmetry on its psychometric properties and on its linkage to measures of emotion and temperament. In addition, future studies are necessary to evaluate more definitively the contribution of cranial and brain asymmetries to anterior EEG asymmetry.

---

[8] Although the results of our recent small study suggest that individual differences in resting anterior EEG asymmetry are not related to differences in measurable cranial or anatomical asymmetries, it may be that measures of absolute power are related to individual differences in skull thickness. In turn, it may be the case that the greater stability of power relative to asymmetry measures is due to the greater effects of skull thickness on the former.

REFERENCES

Amochaev, A., & Salamy, A. (1979). Stability of EEG laterality effects. *Psychophysiology, 16*, 242–246.

Andino, F.L.G., Marqui, R.D.P., Sosa, P.A.V., Lirio, M.B., Machado, C., Diaz, G., Rodriguez, P.F., & Torrez, C.C. (1990). Brain electrical field measurements unaffected by linked earlobes reference. *Electroencephalography & Clinical Neurophysiology, 75*, 155–160.

Beck, A.T., Ward, C.H., Mendelson, M., Mock, J., & Erbaugh, J. (1961). An inventory for measuring depression. *Archives of General Psychiatry, 4*, 561–571.

Blom, J.L., & Anneveldt, M. (1982). An electrode cap tested. *Electroencephalography & Clinical Neurophysiology, 54*, 591–594.

Bryden, M.P. (1982). *Laterality: Functional asymmetry in the intact brain.* New York: Academic Press.

Coppola, R., Karson, C., Daniel, D., & Myslobodsky, M. (1987). EEG asymmetry in relation to skull asymmetry. *Journal of Clinical Neurophysiology, 4*, 282–283.

Cronbach, L.J. (1951). Coefficient alpha and the internal structure of tests. *Psychometrika, 16*, 297–334.

Dabbs, J.M., & Chou, G. (1980). Left-right carotid blood flow predicts specialized mental ability. *Neuropsychologia, 18*, 711–713.

Davidson, R.J. (1988). EEG measures of cerebral asymmetry: Conceptual and methodological issues. *International Journal of Neuroscience, 39*, 71–89.

Davidson, R.J. (in press). Anterior cerebral asymmetry and the nature of emotion. *Brain and Cognition.*

Davidson, R.J., Abramson, L.Y., Tomarken, A.J., & Wheeler, R.E. (submitted). *Asymmetrical anterior temporal brain activity predicts beliefs about the causes of negative life events.* Manuscript submitted for publication.

Davidson, R.J., Chapman, J.P., Chapman, L.J., & Henriques, J.B. (1990). Asymmetrical brain electrical activity discriminates between psychometrically-matched verbal and spatial cognitive tasks. *Psychophysiology, 27*, 528–543.

Davidson, R.J., Ekman, P., Saron, C.D., Senulis, J., & Friesen, W. (1990). Approach/withdrawal and cerebral asymmetry: Emotional expression and brain physiology I. *Journal of Personality and Social Psychology, 58*, 330–341.

Davidson, R.J., & Fox, N.A. (1989). Frontal brain asymmetry predicts infants' response to maternal separation. *Journal of Abnormal Psychology, 98*, 127–131.

Davidson, R.J., Pardington, C., Wheeler, R.E., Doss, R.C., & Tomarken, A.J. (in preparation). *Relations between electrophysiological and neuro-anatomical asymmetries.* Manuscript in preparation.

Davidson, R.J., Schaffer, C.E., & Saron, C. (1985). Effects of lateralized stimulus presentations on the self-report of emotion and EEG asymmetry in depressed and non-depressed subjects. *Psychophysiology, 22*, 353–364.

Davidson, R.J., & Tomarken, A.J. (1989). Laterality and emotion: An electrophysiological approach. In F. Boller & J. Grafman (Eds.), *Handbook of neuropsychology* (pp. 419–441). Amsterdam: Elsevier.

Depue, R.A., & Monroe, S.M. (1978). Learned helplessness in the perspective of the depressive disorders: Conceptual and definitional issues. *Journal of Abnormal Psychology, 87*, 3–20.

Dumermuth, G., & Molinari, L. (1987). Spectral analysis of EEG background activity. In A.S. Gevins & A. Remond (Eds.), *Handbook of electroencephalography and clinical neurophysiology: Methods of analysis of brain electrical and magnetic signals* (Vol. 1, pp. 85–130). Amsterdam: Elsevier.

Dunn, O.J., & Clark, V.A. (1969). Correlation coefficients measured on the same individuals. *Journal of the American Statistical Association, 64*, 366–377.

Ehrlichman, H., & Wiener, M.S. (1979). Consistency of task-related EEG asymmetries. *Psychophysiology, 16*, 247–252.

Epstein, S. (1979). The stability of behavior: I. On predicting most of the people much of the time. *Journal of Personality and Social Psychology, 37*, 1097–1126.

Epstein, S. (1980). The stability of behavior II.: Implications for psychological research. *American Psychologist, 35*, 790–806.

Fein, G., Galin, D., Yingling, C.D., Johnstone, J., & Nelson, M.A. (1984). EEG spectra in 9–13 year-old boys are stable over 1–3 years. *Electroencephalography & Clinical Neurophysiology, 58*, 517–518.

Finman, R., Davidson, R.J., Colton, M.B., Straus, A., & Kagan, J. (1989). Psychophysiological correlates of inhibition to the unfamiliar in children [Abstract]. *Psychophysiology, 26*, S24.

Gasser, T., Bacher, P., & Mocks, J. (1982). Transformations toward the normal distribution of broad band spectral parameters of the EEG. *Electroencephalography & Clinical Neurophysiology, 53*, 119–124.

Gasser, T., Bacher, P., & Steinberg, H. (1985). Test-retest reliability of spectral parameters of the EEG. *Electroencephalography & Clinical Neurophysiology, 60*, 312–319.

Henriques, J.B., & Davidson, R.J. (1990). Regional brain electrical asymmetries discriminate between previously depressed subjects and healthy controls. *Journal of Abnormal Psychology, 99*, 22–31.

Hjorth, B. (1975). An on-line transformation of EEG scalp potentials into orthogonal source derivations. *Electroencephalography & Clinical Neurophysiology, 39*, 526–530.

Kang, D.H., Davidson, R.J., Coe, C.L., Wheeler, R.E., Tomarken, A.J., & Ershler, W.B. (1991). Frontal brain asymmetry and immune function. *Behavioral Neuroscience, 105*, 860–869.

Kraemer, H.C. (1981). Coping strategies in psychiatric clinical research. *Journal of Consulting & Clinical Psychology, 49*, 309–319.

Leissner, P., Lindholm, L.-E., & Petersen, I. (1970). Alpha amplitude dependence on skull thickness as measured by ultrasound technique. *Electroencephalography & Clinical Neurophysiology, 29*, 392–399.

Levy, J. (1983). Individual differences in cerebral hemisphere asymmetry: Theoretical issues and experimental considerations. In J.B. Hellige (Ed.), *Cerebral hemisphere asymmetry: Method, theory, and application* (pp. 465–515). New York: Praeger.

Levy, J., Heller, W., Banich, M.T., & Burton, L.A. (1983). Are variations among right-handed individuals in perceptual asymmetries caused by characteristic arousal differences between the hemispheres? *Journal of Experimental Psychology: Human Perception and Performance, 9*, 329–359.

Lord, F.M., & Novick, M. (1968). *Statistical theories of mental test scores.* Reading, MA: Addison-Wesley.

Lynch, J.J., Paskewitz, D.A., & Orne, M.T. (1974). Intersession stability of human alpha rhythm densities.

Electroencephalography & Clinical Neurophysiology, 36, 538–540.

MacKay, D.M. (1984). Source density analysis of scalp potentials during evaluated action. I. Coronal distribution. *Experimental Brain Research, 54*, 73–85.

Matousek, M., Arvidsson, A., & Friberg, S. (1979). Serial quantitative electroencephalography. *Electroencephalography & Clinical Neurophysiology, 47*, 614–622.

Morgan, A.H., McDonald, P.J., & MacDonald, H. (1971). Differences in bilateral alpha activity as a function of experimental tasks with a note on lateral eye movements and hypnotizability. *Neuropsychologia, 9*, 459–469.

Myslobodsky, M.S., Bar-Ziv, J., van Praag, H., & Glicksohn, J. (1989). Bilateral alpha distribution and anatomic brain asymmetries. *Brain Topography, 1*, 229–235.

Myslobodsky, M.S., Coppola, R., Bar-Ziv, J., Karson, C., Daniel, D., van Praag, H., & Weinberger, D.R. (1989). EEG asymmetries may be affected by cranial and brain parenchymal asymmetries. *Brain Topography, 1*, 221–228.

Nunez, P.L. (1981). *Electric fields of the brain: The neurophysics of EEG.* New York: Oxford University Press.

Nunnally, J.C. (1978). *Psychometric theory.* New York: McGraw-Hill.

Oken, B.S., & Chiappa, K.H. (1988). Short-term variability in EEG frequency analysis. *Electroencephalography & Clinical Neurophysiology, 69*, 191–198.

Oldfield, R.C. (1971). The assessment and analysis of handedness: The Edinburgh Inventory. *Neuropsychologia, 9*, 97–113.

Pollock, V.E., Schneider, L.S., & Lyness, S.A. (in press). Reliability of topographic quantitative EEG amplitude in healthy late-middle-aged and elderly subjects. *Electroencephalography & Clinical Neurophysiology.*

Rushton, J.P., Brainerd, C.J., & Pressley, M. (1983). Behavioral development and construct validity: The principle of aggregation. *Psychological Bulletin, 94*, 18–38.

Sacco, W.P. (1981). Invalid use of the Beck Depression Inventory to identify depressed college students: A methodological comment. *Cognitive Therapy and Research, 5*, 143–147.

Senulis, J.A., & Davidson, R.J. (1989). The effects of linking the ears on the hemispheric asymmetry of EEG [Abstract]. *Psychophysiology, 26*(Suppl.), S54.

Shrout, P.E., & Fleiss, J.L. (1979). Intraclass correlations: Uses in assessing rater reliability. *Psychological Bulletin, 86*, 420–428.

Stassen, H.H. (1980). Computerized recognition of persons by EEG spectral patterns. *Electroencephalography & Clinical Neurophysiology, 49*, 190–194.

Steiger, J.H. (1980). Tests for comparing elements of a correlation matrix. *Psychological Bulletin, 87*, 245–251.

Strube, M.J. (1990). Psychometric principles: From physiological data to psychological constructs. In J.T. Cacioppo & L.G. Tassinary (Eds.), *Principles of psychophysiology: Physical, social, and inferential elements* (pp. 34–57). New York: Cambridge University Press.

Tomarken, A.J., Davidson, R.J., & Henriques, J.B. (1990). Resting frontal brain asymmetry predicts affective responses to films. *Journal of Personality and Social Psychology, 59*, 791–801.

Tomarken, A.J., Davidson, R.J., & Wheeler, R.E. (submitted). *Resting frontal brain asymmetry predicts individual differences in repressive-defensive coping styles.* Manuscript submitted for publication.

Tomarken, A.J., Davidson, R.J., Wheeler, R.E., & Doss, R.C. (1992). Individual differences in anterior brain asymmetry and fundamental dimensions of emotion. *Journal of Personality and Social Psychology, 62*, 676–687.

Van Dis, H., Corner, M., Dapper, R., Hanewald, G., & Kok, H. (1979). Individual differences in the human electroencephalogram during quiet wakefulness. *Electroencephalography & Clinical Neurophysiology, 47*, 87–94.

Wheeler, R.G., Davidson, R.D., Tomarken, A.J., & Kinney, L. (in press). Resting frontal asymmetry and emotional reactivity: A biological substrate of affective style. *Psychophysiology.*

Winer, B.J. (1971). *Statistical principles in experimental design* (2nd ed.). New York: McGraw-Hill.

(Manuscript received November 18, 1990; accepted for publication June 25, 1991)