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Long-Term Stability of Electroencephalographic Asymmetry and Power in 3 to 9 Year Old Children

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Abstract

We investigated test-retest stability of resting EEG asymmetry and power in the alpha frequency range across a 0.6 - to 3-year interval in 125 children (57 girls and 68 boys) for two age groups, 87 preschool children (3 to 5 year-olds) and 38 school-age children (6 to 9 year-olds). Children were from families with a parent's history of unipolar or bipolar depression (36 girls and 43 boys) or control families with no parent history of depression nor any other psychiatric disorder (21 girls and 25 boys). Frontal EEG asymmetry stability was low to moderate; intraclass correlations ranged from zero to 0.48 in the eyes-open condition, and from 0.19 to 0.45 in the eyes-closed condition. Also, parietal EEG asymmetry was low to moderate; intraclass correlations ranged from 0.21 to 0.52 in the eyes-open condition and from 0.27 to 0.72 in the eyes-closed condition. Stability of EEG asymmetry was not related to age, sex of the child, or parent's history of mood disorder. Frontal and parietal EEG power appeared moderately to highly stable. Intraclass correlations were between 0.65 and 0.86 in the eyes-open condition and between 0.52 and 0.90 in the eyes-closed condition. Although stability of EEG power was not statistical significantly different between preschool and school-age children, it consistently showed higher stability values in school-age children than in preschool children. Stability in school-aged children approached values as has been reported for adults. The findings provide partial support to the concept of frontal EEG asymmetry as a trait marker in childhood.

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Keywords

Stability; longitudinal study; EEG asymmetry; EEG power; development; sex; depression

Introduction

The pattern of resting frontal EEG asymmetry[1] in the alpha frequency band, the relative imbalance of bioelectrical cerebral activity recorded from the left frontal scalp locations and the corresponding right locations, is believed to reflect affective style and motivational bias in both children and adults (Tomarken & Keener, 1998;Sutton & Davidson, 1997;Fox, 1991;Davidson et al., 1990;Tomarken et al., 1990;Davidson & Tomarken, 1989;Davidson, 1988). Left EEG asymmetry refers to positive EEG asymmetry values indicating greater left relative to right brain activity and right EEG asymmetry refers to negative (and zero) EEG asymmetry values yielding the opposite activity pattern. This is because brain activity is regarded as the inverse of alpha power (Shagass, 1972). The adult literature on EEG asymmetry during resting conditions suggests that the tendency to react with approach motivation (readiness to be engaged with the environment) and to experience positive affect are reflected by left EEG asymmetry, whereas a negative motivational bias (the tendency to withdraw) and to experience negative affect are captured by right EEG asymmetry (Shankman et al., 2003, 2005;Baving et al., 2003;McManis et al., 2002;Tomarken and Keener, 1998;Sutton and Davidson, 1997;Fox, 1991;Davidson et al., 1990;Henriques and Davidson, 1990;Tomarken et al., 1990;Davidson & Fox, 1989;Davidson and Tomarken, 1989). Thus, these physiological indexes are believed to measure emotional and temperamental personality predispositions. As such, individuals displaying left frontal EEG asymmetry often exhibit approach motivation and positive affect while individuals displaying right EEG asymmetry have been found to exhibit withdrawal and negative affect. This proposition has received support in studies of child temperament and behavior (Shankman et al., 2003,2005;Baving et al., 2003;McManis et al., 2002;Fox, 1991;Davidson & Fox, 1989).

Implicit in the research utilizing frontal EEG asymmetry is the assumption that this index reflects a stable individual characteristic, or trait. Stability of frontal EEG asymmetry has been assessed in different age groups covering infancy (Jones et al., 1997; Fox et al., 1992) and adulthood (Vuga et al., 2006; Hagemann et al., 2002; Tomarken et al., 1992). Fox et al. (1992) found fair to moderate stability in frontal EEG asymmetry across a 1 month interval (Pearson correlation: 0.3 – 0.5) but lack of stability across 5 months (Pearson correlation: −0.2). On the other hand, Jones et al. (1997) reported that frontal EEG asymmetry was moderately stable across a 2- to 2.5-year interval in infants aged 3- to 6- months at baseline (Pearson correlation: 0.7). Research with adults shows moderate long-term stability in frontal EEG asymmetry. Stability of around 0.6 was observed in all 3 adult studies (using intraclass correlation in Vuga et al., 2006 and Hagemann et al., 2002 and Pearson's correlation in Tomarken et al., 1992). To the best of our knowledge, there are no published reports on stability of EEG asymmetry in children 3 years of age and older.

Even though the relation between emotion and EEG asymmetry is specific to frontal sites, it is important to evaluate stability of parietal EEG asymmetry. Parietal asymmetry has been examined in many studies of child behavior and development (Baving et al., 2003; Jones et al., 2001; Anokhin et al., 2000) and these sites are differentially involved in brain development (Anokhin et al., 2000; Martincovic et al., 1998; Gasser et al., 1988b; Thatcher et al., 1987; Matousek and Petersen, 1973). While stability of parietal EEG asymmetry in children is not

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[1] The phrase "EEG asymmetry" will signify resting EEG asymmetry in the respective alpha frequency range throughout the entire article, unless otherwise stated.

yet known, in adults the coefficients range from about 0.6 to 0.7 (Vuga et al., 2006; Hagemann et al., 2002).

Frontal EEG asymmetry is a computed measure of the difference in alpha power between homologous leads in right and left frontal scalp locations. However, EEG power itself reflects electrical activity of neuron groups and neural network organization in specific brain areas (Nunez, 1981). Changes in mean EEG power are related in myriad ways to the development of the brain (Clarke et al., 2001; Anokhin, 2000; Martincović et al., 1998; Van Baal et al., 1996; Gasser et al., 1988a; Benninger et al., 1984; Katada et al., 1981; Matthis et al., 1980). For example, a recent study reports a pattern of increase for most sites in infants and preschool children from 5 to 10 months of age till the age of 2 to 4 years (Marshall et al., 2002); stability coefficients were 0.70 and 0.75 on the right and left, respectively, for frontal EEG power in 2- to 4- year-olds and for the same time range, the coefficients for parietal EEG power were 0.59 and 0.67 on the right and left, respectively. In children aged 10 to 13 years, stable frontal EEG power in the moderate to high range (0.71 – 0.74) were reported during eyes-closed condition across a one year period (Gasser et al., 1985). In children aged 4 to 10 years, long-term stability across a 1-year interval was also reported (Benninger et al., 1984). In adults, EEG frontal and parietal power were highly stable (e.g., intraclass correlation between 0.85 and 0.91 across about a year interval, Vuga et al., 2006; rank correlation coefficients between 0.78 and 0.86 across a 3–4 months interval, Salinsky et al., 1991).

A number of factors may influence the stability of frontal EEG asymmetry and power including sex, handedness of the participant, parental history of depression, and normal brain development. Reports in the literature suggest that there are sex differences in brain organization (Negri-Cesi et al., 2004; Levy & Heller, 1992; Galaburda et al., 1990). In children ranging from infancy to age 3, studies on stability of EEG asymmetry were based on small groups and consequently sex differences could not be evaluated due to insufficient statistical power (Jones et al., 1997; Fox et al., 1992). In adults, sex was found to be unrelated to stability of EEG asymmetry (Vuga et al., 2006). Handedness may be an important factor influencing stability due to the differential brain organization of left and right handed individuals (Galaburda et al., 1990; Hardyck & Petrinovich, 1977). In prior studies of frontal EEG asymmetry with children, handedness was either restricted to right-handers or ignored (Rybak et al., 2006; Santesso et al., 2006; Shankman et al., 2005). In studies with adults, handedness was found to have negligible effect on stability of EEG asymmetry (Vuga et al., 2006). Parental history of depression also may affect stability of frontal EEG asymmetry among young offspring. Specifically, parental depression has been found to have an impact on a child’s emotional development (Gotlib & Goodman, 1999; Silk et al., 2006; Caplan et al., 1989). Previous studies have found differences in frontal EEG asymmetry among young children (Forbes et al., 2006) or adolescent offspring (Tomarken, et al., 2004) of parents with a history of depression. Finally, stability of frontal EEG asymmetry among youngsters may be influenced by the ongoing structural and functional brain development across the childhood years (Kanemura et al., 2003; Luciana & Nelson, 1998; Creutzfeld, 1995). Given increasing brain maturity, older children could be expected to evidence greater stability in indices of EEG than younger children.

Goal of the Current Study

The goal of the current study was to examine stability of EEG asymmetry and power among 3- to 9-year-old children. Alpha was the band of primary interest because EEG alpha power is associated with attention (Niedermeyer, 1999) and previous research findings on EEG asymmetry linked this band specifically with individual differences, emotional states, and depression (Davidson, 1995; for a review article see Coan & Allen, 2004). We computed frontal and parietal EEG asymmetry and power from EEG measured at two occasions across a period of about one year. Our study population consisted of children with and without a parent's history of depression. We tested whether EEG asymmetry represents a stable individual characteristic during both the preschool and school age periods. We expected that the magnitude of stability of both EEG power and EEG asymmetry would be greater in older than younger children (3–5 and 6–9 years of age). Furthermore, we evaluated the influence of sex, handedness, and parental history of depression.

Method

Participants

This study group was comprised of children between the ages 3 and 9 at their first EEG session whose parents participated in a multidisciplinary Program Project of research on risk factors for childhood-onset depression (COD). Proband parents were those with COD, operationally defined as a DSM-based psychiatric diagnosis (American Psychiatric Association, 1980, 1994) of major depressive and/or dysthymic disorder by age 14 or bipolar spectrum disorder (bipolar I, bipolar II, or cyclothymic disorder) by age 17. COD parents were enrolled from several sources, including a longitudinal naturalistic follow-up study of childhood depression (Kovacs et al., 1997) or because they had previously participated in various time-limited research studies, or were recruited from the community. Control parents, also recruited from multiple sources, had no history of major psychiatric disorder. Those children who completed two psychophysiological assessments were included in this study. For more details on the recruitment and diagnostic procedures, see Miller et al. (2002).

The originally available sample included 134 cases: 7 were eliminated because the test-retest interval exceeded 3 years and 1 other participant was eliminated due to unusable EEG data. The final group of 125 participants included 79 children with a parental history of unipolar depression (N = 58) or bipolar depression (N = 21), and 46 children of control parents. There were more preschoolers (N=87) than school-age children (N=38) with an equal ratio of offspring of depressed parents (63%) and offspring of controls (37%) in each age group; 55 preschool children and 24 school-age children had a parent with a history of depression. Several children in the group were siblings: 72 families contributed 1 child each (46 preschool children, 26 school-age children), 18 families contributed 2 children each (30 preschool children, 6 school-age children), 3 families contributed 3 children each (6 preschool children, 3 school-age children), and 2 families contributed 4 children each (5 preschool children, 3 school-age children).

Table 1 presents the demographic information. Preschool children, aged 3 to 5 years, and school-age children, aged 6 to 9 years, included 47 boys and 40 girls and 21 boys and 17 girls, respectively. The two age groups were comparable with respect to demographic data. The time between EEG assessments ranged from about half a year (0.56 years) to about three years (2.94 years) and was comparable for both age groups.

Procedures

EEG data acquisition—Prior to each of the two EEG recording sessions, assent was obtained from each child and written informed consent was obtained from the child's guardian. Handedness was determined at Time 1 according to the Edinburgh Handedness Inventory (Oldfield, 1971). EEG was acquired based on standard guidelines (Pivik et al., 1993). An electrode cap (ElectroCap, Eaton, Ohio) was positioned according to the International 10–20 System (American Electroencephalographic Society, 1994). Electrodes were placed at sites F3, F4, F7, F8, C3, C4, T7, T8, P3, P4, O1, and O2. For two children, EEG was additionally obtained from the following sites AF3, AF4, Fz, FC1, FC2, FC5, FC6, P7, and P8. Recordings were made with AFz ground against a vertex (Cz) reference. This reference site was used for recording purpose only. Cz-referenced data was not intended to be utilized for data analysis because it has been discouraged from use especially for frontal sites (Hagemann et al., 2001).

A vertical electro-oculogram (EOG) channel and was recorded in a bipolar manner to obtain eye blink and eye movement signals. A vertical EOG channel is composed of two six mm tin electrodes that were placed above and to the side of the right eye. An additional horizontal EOG channel was applied to all children 6 years-old or older at their second visit; electrodes were placed above and below the right eye, and on the outer canthi for the vertical and horizontal EOG, respectively.

Scalp electrode impedances were required to be below 5 kΩ with pairs of homologous sites within 0.5 kΩ of each other. The bioamplifier was set for band-pass filtering with half-power cutoff frequencies of 1 and 100 Hz. Setting of 0.01 and 100 Hz were applied to children aged 6 or older years at their second visit. A gain of 5000 and 2500 was used for EEG channels and EOG channels, respectively. Data were acquired with equipment and software from the James Long Company (Caroga Lake, N.Y.) using a sampling rate of 512 Hz.

The sessions took place in a room decorated in a space theme. For eyes-open condition, participants were instructed to look at a small spaceship in front of a television screen; two were instructed to look at a small star presented on the screen. For eyes-closed condition, instructions were to sit comfortably with their eyes-closed. EEG data were obtained from each participant during six 30 seconds resting baseline periods with eyes-open (O) or eyes-closed (C). These two conditions were presented in alternating order starting with eyes-open condition (OCOCOC).

EEG data reduction—Signal quality was evaluated during a brief manual review. Subsequently, an automated routine was used to eliminate artifacts. The routine excluded periods that were above a 180μV threshold, eliminating artifacts resulting from movements, large scale muscle tension, sweat, and large eye movements. For verification, reliability of automated artifact elimination procedure used in this study was compared against manually artifact-scored data in a subset of 44 participants (22 pre-school and 22 school-age children). Intraclass correlations of EEG alpha power between the two methods ranged from 0.94 to 0.99 in 3 to 5 years olds and from 0.95 to 0.99 in 6 to 9 years olds in the eyes-open condition and from 0.95 to 1.00 in 3 to 5 years olds and from 0.99 to 1.00 in 6 to 9 years olds in the eyes-closed condition. Thus, automated artifact-scored data reported here were comparable to manually artifact scored data. EEG data were then re-referenced to a common average reference. Fourier analyses were applied to each 30-second baseline epoch using one-second artifact-free Hanning-windowed data with 50% overlap in each epoch.

To capture the major age-specific spectral alpha activities, different alpha bands have been proposed for pre-school children and school-age children. Following the evaluation of power distribution in preschool children (e.g., Marshall et al., 2002), alpha corresponded to 6.5 to10.5 Hz in 3 to 5 year-olds. The alpha band was shifted by 1 Hz from preschool children to school-age children based on the difference in their age-dependent peak frequencies (8 Hz in preschool children and 9 Hz in school-age children; Niedermeyer, 1999). Therefore, alpha corresponds to 7.5 to 11.5 Hz in 6 to 9 year-olds; these band definitions have been previously used by Forbes et al. (2006). Power spectral density (in μV^2) was averaged across the two baseline conditions (eyes-open, eyes-closed) separately and weighted by the number of artifact-free windows in each condition.

To normalize the distribution, EEG alpha power values were natural logarithm-transformed (Gasser et al., 1982). EEG asymmetry scores were computed as the difference between natural logarithm (ln) of EEG alpha power at the right recording site and the left recording site (ln (right) - ln (left); e.g., F3/4 = ln (F4) - ln (F3)). Brain activity is an inverse measure of alpha power activity, meaning less alpha power represents more brain activity and vice versa (Shagass, 1972). Consequently, left EEG asymmetry values indicate greater left relative to right brain activity, and right EEG asymmetry values yield the opposite activity pattern. EEG asymmetries were evaluated for mid frontal (F3, F4), lateral frontal (F7, F8), and parietal (P3, P4) pairs of sites. Although anterior temporal sites (T7, T8) are commonly used (e.g., Davidson et al., 1990), we did not include these sites, as signals at these leads tend to show substantial amounts of artifact (Vuga et al., 2006; Papousek & Schulter, 2004). Six children in the 3- to 5-year-old age group and one in the 6- to 9-year-old age group were excluded in the eyes-closed condition because they had difficulties keeping their eyes-closed which resulted in unusable data.

To ensure that a potential difference in results for the two age groups is unrelated to different amount of EEG in the various groups, we compared the amount of EEG data used in analysis; it was approximately equivalent for both age groups at both assessments (for visit 1: 3–5 year-olds: *MEDIAN*=83 s, 6–9 year-olds: *MEDIAN*=84.3 s, in the eyes-open condition and 3–5 year-olds: *MEDIAN*=80.5 s, 6–9 year-olds: *MEDIAN*=84.5 s, in the eyes-closed condition; Kruskal-Wallis test, χ^2=0.08, p=0.78 for the eyes-open condition and χ^2=0.59, p=0.44 for the eyes-closed condition) and did not differ for the different assessments (Kruskal-Wallis test, χ^2=1.39, p=0.24 across age groups, χ^2=0.58, p=0.45 for pre-school children and χ^2=0.69, p=0.41 for school-age children).

Results

Stability of EEG asymmetry

Table 2 presents the mean values and standard deviations for EEG asymmetry at both visits. Stability was assessed using intraclass correlations (ICC), based on a random effects model (Shrout and Fleiss, 1979), and was computed for the entire group, and for the two age groups (3–5 year-olds, 6–9 year-olds), as can be seen in Table 3. We used the following guidelines to interpret stability values: “low” stability refers to values smaller than 0.4, “moderate” to values 0.4 to smaller than 0.7, and “high” to values 0.7 and greaterr (Cronbach, 1972).

For the eyes-open condition, EEG asymmetry was stable in all brain regions for both age groups, except in lateral frontal and mid-frontal region for school-age children and parietal region for preschool children. For the eyes-closed condition, EEG asymmetry was stable in all brain regions for all age groups, except in lateral frontal region for both age groups. In the entire group, EEG asymmetry scores showed low to moderate stability for all regions; stability was low in the eyes-open condition (0 – 0.48) and eyes-closed condition (0.19 – 0.72). For 3 to 5 year-olds, stability was low to moderate; ranging from 0.21 to 0.48 in the eyes-open condition and 0.21 to 0.31 in the eyes-closed condition. For 6 to 9 year-olds, stability varied widely, ranging from 0 to 0.52 in the eyes-open condition and 0.19 to 0.72 in the eyes-closed condition.

For the three repeated EEG asymmetry values, based on the two baseline conditions, testing differences in slopes between the two age-groups yielded statistically non-significant results (Table 3). This test (based on composing an ANOVA of EEG asymmetry at Time 2 on a full factorial model of age-group and EEG asymmetry at Time 1) allowed us to test the null hypothesis that the effect of EEG asymmetry at Time 1 on EEG asymmetry at Time 2 did not vary across age-groups. The lack of statistically significant differences across age groups in stability of EEG asymmetry is consistent with the wide 95% confidence intervals, computed using the approach by Shrout and Fleiss (1978).

Stability of EEG power

Table 4 presents the mean values and standard deviations for EEG power at both visits. Stability in EEG power was computed for the entire group and for the two age groups (3–5 year-olds, 6–9 year-olds), separately, and are presented in Table 5 for eyes-open and eyes-closed conditions. In the entire group, EEG power values were highly stable, with coefficients ranging from 0.74 to 0.78 in the eyes-open, and from 0.64 to 0.79 in the eyes-closed condition (Table 5). For 3 to 5 year-olds, power values were stable in the eyes-open condition (0.65 – 0.71) and eyes-closed condition (0.52 –0.70). For 6 to 9 year-olds, power values were stable in the eyes-open condition (0.70 –0.86) and eyes-closed condition (0.76 – 0.90).

To test for between-group differences in stability of EEG power, we conducted an ANOVA of EEG power at Time 2 on a full factorial model of age group (3–5 years, 6–9 years) and EEG power at Time 1. There was no statistically significant difference in stability as a function of age group (see Table 5), which may correspond to the wide 95% confidence intervals.

Effects of covariates

To evaluate the effects of covariates on the stability of EEG asymmetry and power, we studied first factors with substantial representation in each subgroup, namely: sex of child (57 girls vs. 68 boys) and parental history of depression (46 normal parents vs. 79 parents with a history of depression). Second, we evaluated factors with sparse data in one of two subgroups; specifically: handedness (13 left-handers), variations in time between sessions (14 with a time interval longer than 1.5 years), multiple siblings in families (23 families with multiple siblings; 19 with multiple siblings within an age group), and overlap between age groups (28 were older than age group at the child's second visit).

To test for between-subgroup differences in stability, we conducted an analysis of variance (ANOVA) of EEG asymmetry at Time 2 on a full factorial model of group (parental history of depression, no parental history of depression), sex of child (girl, boy), and EEG asymmetry at Time 1. The test for differences between covariates was not statistically significant in the eyes-open condition (EEG asymmetry: all $F(3, 117) \leq 0.08$, all $p \geq 0.96$; EEG power: all $F(3, 117) \leq 0.01$, $p \geq 0.99$) and in the eyes-closed condition (EEG asymmetry: all $F(3, 110) \leq 0.55$, all $p \geq 0.73$; EEG power: all $F(3, 110) \leq 0.03$, $p \geq 0.99$; with fewer data available in this baseline condition). Consequently, stability of EEG asymmetry and power were unrelated to parent's history of depression and sex of child. As such, stability values for these subgroups are not presented.

To evaluate factors with low representation in one subgroup, we computed stability for the entire group and then excluding the rare condition. We computed differences in stability between all participants and right-handed participants (N = 112); differences were minimal for the entire group (EEG asymmetry: *MEAN* = 0.01, *SD* = 0.01; EEG power: *MEAN* = −0.01, *SD* = 0.01), the 3–5 year-olds (N=78; EEG asymmetry: *MEAN* = 0.01, *SD* = 0.02; EEG power: *MEAN* = −0.01, *SD* = 0.01), and the 6–9 year-olds (N = 34; EEG asymmetry: *MEAN* = −0.01, *SD* = 0.05; EEG power: *MEAN* = 0.01, *SD* = 0.04).

Because of variations in time between sessions that were substantial although not statistically significantly different between age groups (refer to Table 1), we examined the effect of the re-test interval. We computed stability for only those participants who had their follow-up visit within 1.5 years (N = 102); differences in stability between all participants and those with a shorter follow up time were minor (EEG asymmetry: *MEAN* = 0.003, *SD* = 0.03; EEG power: *MEAN* = −0.04, *SD* = 0.03).

To address non-independence among siblings, we randomly selected the one sibling within each age group to remain in the data set. Those that were not drawn from the two age groups were removed, resulting in the exclusion of 22 children: 19 and 3 children in the 3- to 5-year-olds and 6- to 9- year-olds, respectively. Due to missing data in the eyes closed condition, 20 participants were eliminated: 17 and 3 children in the 3- to 5-year-old and 6- to 9- year-old groups, respectively. Differences in age-specific stability coefficients between all participants and participants with one sibling per family per age group were small (EEG asymmetry: 3–5 year-olds: *MEAN* = −0.05, *SD* = 0.04, 6–9 year-olds: *MEAN* = 0.01, *SD* = 0.04; EEG power: 3–5 year-olds: *MEAN* = −0.01, *SD* = 0.01, 6–9 year-olds: *MEAN* = 0.01, *SD* = 0.01).

Twenty-three percent of children had their Time 2 visit beyond the time limits of their age group at intake, i.e., 29 preschool children at intake were 6 years or older at Time 2. To eliminate confounding due to age group outliers at the second visit, we removed these children from the analyses, thereby reducing the group to 58 children between 3 and 5 years old. The stability results were essentially unchanged (EEG asymmetry: *MEAN* = 0.04, *SD* = 0.11; EEG power: *MEAN* = −0.03, *SD* = 0.0).

Discussion

The goal of this study was to evaluate the long term stability of EEG asymmetry and power in children 3- to 9-years of age. Across about a one year interval, EEG asymmetry stability was low to high and mostly at a moderate level in mid-frontal, lateral frontal, and parietal regions at similar levels in both preschoolers and school-age children. Sex of the child, handedness, or history of parental depression did not affect stability. These data extend the EEG stability findings in adults, which have shown no effects of history of depression (Vuga et al., 2006) and sex (Vuga et al., 2006; Hagemann et al., 2002).

Although the magnitude of long-term stability in frontal EEG asymmetry in the current study was lower than long-term stability figures previously reported from infancy to early childhood (Jones et al., 1997), it fell between the 5-month stability in infants (Fox et al., 1992) and the 1-year stability in adults (Vuga et al., 2006). The discrepancy in stability reported by studies of infants warrants further research.

Larger variability in EEG asymmetry of parietal sites than frontal sites, as shown in Table 2, is concordant with findings in 7 to 8 year-olds (Anokhin et al., 1996) and 10 year-olds (McManis et al., 2002). Posterior sites show about twice as much spread than frontal sites in 6 to 17 year-olds (Gasser et al., 1988b) and in healthy 11 year-olds (Baving et al., 2003). The range of parietal EEG asymmetry values in the current study is comparable with that reported for adults (Vuga et al., 2006).

Contrary to our hypothesis, we failed to detect developmental changes in stability of EEG asymmetry across the age groups we studied, namely, preschoolers versus young school-age children. A developmental shift in stability of EEG asymmetry may have occurred earlier or could take place later in development. This study presented the magnitude of EEG asymmetry stability in children based on the commonly used age groupings, preschool and school-age. For these age groups, there was no developmental difference in stability. This parallels the findings of mean EEG asymmetry by age (Forbes et al., 2006; Matthis et al., 1980). This means EEG asymmetry values are stable at similar levels for these two age groups. Further studies should include a finer gradation by age, which may reveal developmental changes in stability of EEG asymmetry.

EEG power was moderately stable across a 0.6- to 3-year interval for 3–5 year-olds and 6–9 year-olds. EEG power stability in 6–9 year-olds was comparable with figures previously reported in pre-adolescent children (Gasser et al., 1985; Fein et al., 1984). According to a report by Marshall et al., (2002), a subtle trend of continuous increase was observed in EEG power stability from infancy. Based on our study, this trend seems to continue across preschoolers and school-age children, possibly reflecting brain maturation (Thatcher et al., 1987).

One notable aspect of our findings is that the stability coefficients were consistently lower for EEG asymmetry as compared to EEG power. This can be explained by evaluating the composition of the common EEG power component that cancels in the computation of EEG asymmetry. This common component includes both common stable activity and common unstable activity (based on the concept of decomposition into systematic and random components presented by Krippendorff, 1970). When the common component contains more stable activity at each assessment, then stability for EEG asymmetry will be lower than for EEG power. When the common component contains more unstable activity at each assessment, then stability for EEG asymmetry will be higher than for EEG power. Given that EEG asymmetry is always lower than either of the EEG power values it is composed of, the common stable power component is larger than the unstable part. Consequently, the lower stability for EEG asymmetry compared with EEG power corresponds to the elimination of the high amount of common stable components in the involved EEG power measures.

To the best of our knowledge, our study is the first to report on the long-term stability of EEG asymmetry in children aged 3 to 9 years. The results provide some support for the hypothesis that frontal EEG asymmetry may be a trait marker in childhood. Further, among all frontal brain regions, mid frontal EEG asymmetry in the eyes-closed condition appears to be the most promising candidate for trait characteristic in children 3- to 9-years of age. Finally, the results also underscore the need for further studies of children of various ages in order to advance our understanding of the trait implications of EEG asymmetry for the entire developmental spectrum.

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Table 1

Participant Information

Variables			Age					
	Entire sample		3–5 years		6–9 years		Statistical Effect	
A. Categorical Variables							χ^2	*p*-value
N	125		87		38			
Sex (% boys)	54.4		54.0		55.3		0.02	0.90
Race (% White)	53.6		57.5		44.7		1.72	0.19
Handedness (% Right)	89.6		89.7		89.5		-	1.00[&]
B. Continuous Variables	*MEAN*	*SD*	*MEAN*	*SD*	*MEAN*	*SD*	$\chi^{2\,\$}$	*p*-value
Age at Time 1 (years)	5.2	1.7	4.2	1.0	7.4	0.9	78.72	<0.0001
Interval (years)	1.2	0.5	1.2	0.5	1.1	0.4	0.00	0.99

[$] Kruskal-Wallis test with 1 degree of freedom;

[&] Fischer’s Exact test

Table 2

EEG Asymmetry at Time1 and Time2 for both Age Groups

Asymmetry Means (SD)	**3–5 years**		**6–9 years**	
	Time 1	**Time 2**	**Time 1**	**Time 2**
		Eyes-open		
N	87	87	38	38
Mid frontal	−0.02 (0.16)	−0.03 (0.16)	0.03 (0.17)	0.01 (0.15)
Lateral frontal	−0.01 (0.18)	−0.00 (0.18)	−0.02 (0.16)	0.00 (0.17)
Parietal	−0.04 (0.20)	−0.04 (0.19)	−0.10 (0.20)	−0.04 (0.21)
		Eyes-closed		
N	81	81	37	37
Mid frontal	−0.02 (0.14)	−0.02 (0.13)	0.01 (0.11)	0.02 (0.13)
Lateral frontal	−0.02 (0.14)	0.01 (0.15)	0.00 (0.12)	0.00 (0.12)
Parietal	0.08 (0.29)	0.10 (0.35)	0.15 (0.44)	0.13 (0.35)

Table 3

Stability of EEG Asymmetry across Time

Asymmetry	Stability			Least Square Means		Statistical Age Effect	
	Entire sample	**3–5 years**	**6–9 years**	**3–5 years**	**6–9 years**	***F*-value**	***p*-value**$^{\Delta}$
		Eyes-open					
N	125	87	38				
Mid frontal	0.40*	0.48*	0.18	−0.023	0.007	0.26	0.70
Lateral frontal	0.24*	0.34*	0.00	−0.004	0.003	1.98	0.39
Parietal	0.31*	0.21	0.52*	−0.044	−0.016	0.26	0.70
		Eyes-closed					
N	118	81	37				
Mid frontal	0.35*	0.31*	0.45*	−0.020	0.017	0.09	0.81
Lateral frontal	0.21*	0.21	0.19	0.010	0.003	0.02	0.91
Parietal	0.46*	0.27*	0.72*	0.120	0.097	0.07	0.84

[*] significantly different from zero based on the confidence interval around the intraclass correlation;

[Δ] Test of differences in Time 1 by Time 2 association across age groups (test of interaction to evaluate differences between slopes)

Table 4

EEG Power Means at Time1 and Time2 for both Age Groups

Power **Means (SD)**	**3–5 years**		**6–9 years**	
	Time 1	**Time 2**	**Time 1**	**Time 2**
		Eyes-open		
N	87	87	38	38
Left Mid Frontal	2.99 (0.48)	2.86 (0.45)	2.49 (0.49)	2.36 (0.50)
Right Mid Frontal	2.96 (0.48)	2.83 (0.45)	2.52 (0.45)	2.38 (0.46)
Left Lateral Frontal	2.99 (0.41)	2.87 (0.43)	2.48 (0.45)	2.34 (0.45)
Right Lateral Frontal	2.98 (0.39)	2.86 (0.44)	2.46 (0.44)	2.34 (0.46)
Left Parietal	2.98 (0.59)	2.91 (0.59)	2.57 (0.65)	2.50 (0.69)
Right Parietal	2.95 (0.58)	2.87 (0.57)	2.47 (0.57)	2.46 (0.65)
		Eyes-closed		
N	81	81	37	37
Left Mid Frontal	3.42 (0.48)	3.38 (0.51)	3.11 (0.70)	2.97 (0.74)
Right Mid Frontal	3.40 (0.50)	3.37 (0.50)	3.12 (0.68)	3.00 (0.70)
Left Lateral Frontal	3.43 (0.48)	3.40 (0.50)	3.11 (0.63)	2.97 (0.70)
Right Lateral Frontal	3.41 (0.49)	3.41 (0.48)	3.11 (0.64)	2.97 (0.68)
Left Parietal	3.68 (0.67)	3.72 (0.62)	3.55 (0.84)	3.41 (0.91)
Right Parietal	3.76 (0.69)	3.82 (0.75)	3.69 (0.92)	3.54 (1.00)

Table 5

Stability of EEG Power across Time

		Stability		Least Square Means		Statistical Effect	
EEG Power	**Entire sample**	**3–5 years**	**6–9 years**	**3–5 years**	**6–9 years**	***F*-value**	***p*-value$^{\Delta}$**
		Eyes-open					
N	125	87	38				
Left Mid Frontal	0.76*	0.68*	0.77*	2.77	2.64	0.01	0.93
Right Mid Frontal	0.74*	0.65*	0.78*	2.75	2.63	0.02	0.91
Left Lateral Frontal	0.78*	0.71*	0.72*	2.75	2.61	0.00	1.00
Right Lateral Frontal	0.76*	0.69*	0.70*	2.74	2.61	0.00	0.99
Left Parietal	0.75*	0.65*	0.86*	2.83	2.76	0.03	0.89
Right Parietal	0.77*	0.69*	0.83*	2.77	2.77	0.03	0.89
		Eyes-closed					
N	118	81	37				
Left Mid Frontal	0.77*	0.62*	0.88*	3.36	3.16	0.04	0.87
Right Mid Frontal	0.77*	0.63*	0.90*	3.34	3.17	0.06	0.85
Left Lateral Frontal	0.79*	0.68*	0.86*	3.37	3.17	0.03	0.89
Right Lateral Frontal	0.79*	0.70*	0.86*	3.38	3.15	0.03	0.89
Left Parietal	0.64*	0.52*	0.76*	3.74	3.47	0.08	0.83
Right Parietal	0.69*	0.55*	0.85*	3.86	3.56	0.06	0.85

[*] significantly different from zero based on the confidence interval around the intraclass correlation;

[Δ] Test of differences in Time 1 by Time 2 association across age groups (test of interaction to evaluate differences between slopes)