

A Comparison of the Electroencephalogram between Institutionalized and Community Children in Romania

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Abstract

■ Electroencephalographic (EEG) data were collected from a sample of institutionalized infants and young children in Bucharest, Romania, and were compared with EEG data from age-matched children from the local community who had never been institutionalized and who were living with their families in the Bucharest area. Compared with the never-institutionalized group, the institutionalized group showed a pattern of increased low-frequency (theta) power in posterior scalp regions and decreased high-frequency (alpha and beta) power,

particularly at frontal and temporal electrode sites. This finding is consistent with EEG studies of children facing environmental adversity and children with learning disorders. The institutionalized group also showed less marked hemispheric EEG asymmetries than the never-institutionalized group, particularly in the temporal region. The results are discussed in the context of two models: that the pattern of EEG in the institutionalized children reflects a maturational lag in nervous system development, or that it reflects tonic cortical hypoactivation. ■

INTRODUCTION

Institutionalization has been shown to have dramatic consequences for children's development across a variety of domains (for reviews, see Zeanah et al., 2003; Gunnar, 2001). However, the consequences of institutionalization on central nervous system (CNS) functioning have received little attention. One exception is a positron emission tomography study of 10 children (mean age, 8 years) who had been adopted into North America after living in a Romanian institution (Chugani et al., 2001). Nearly all children had been placed in the institution before 1.5 months of age and had lived in the institution for an average of 38 months before being adopted. Compared to control groups of healthy adults and 10-year-old children with refractory epilepsy, the adoptees showed significantly reduced brain activation in a number of brain areas believed to be involved in higher cognition, emotion, and emotion regulation. These areas included regions of orbitofrontal and infra-limbic cortex as well as medial temporal lobe structures such as the amygdala. Although the work of Chugani et al. (2001) is distinctive in examining functional brain activity after early institutionalization, a number of other studies have examined physical, cognitive, and socio-emotional outcomes in postinstitutionalized children from Romania after they had been adopted by families in North America or the United Kingdom (e.g., Rutter & O'Connor, 2004; Rutter, Kreppner, & O'Connor, 2001;

Chisholm, 1998). These studies have been informative, although there remains a lack of contemporary studies of children while they are living in an institution. In the present study, we use electroencephalographic (EEG) techniques to examine CNS functioning in a sample of infants and young children living in an institution in Bucharest, Romania. For comparison, we also examine the EEG in an age-matched group of children who have never been institutionalized and who live with their families in the greater Bucharest area. The present study is therefore unique in recording neurophysiological measures from infants and children living in an institution. For the full context of the study, the reader is referred to Zeanah et al. (2003).

The EEG is a relatively inexpensive and noninvasive method of recording brain activity using individual electrodes distributed over the surface of the scalp. Several inherent properties of cortical circuits produce an ongoing rhythmicity in the EEG signal, which may be decomposed into oscillations occurring in different frequency bands with specific functional correlates and physiological origins (Niedermeyer & da Silva, 1993). For the quantification of electrical activity within each frequency band, the digitized EEG data are typically edited for motor and muscle artifact, and samples of artifact-free data are analyzed using a Fourier transform to quantify the spectral power in the EEG signal. Examples of functionally different frequency bands and their frequency ranges in adults include delta (1–3 Hz), theta (4–7 Hz), alpha (8–13 Hz), and beta (14–20 Hz), with the boundaries of the frequency bands being

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lower in infants and young children. For instance, 6–9 Hz appears to be a suitable alpha-range band in infancy and early childhood (Marshall, Bar-Haim, & Fox, 2002; Stroganova, Orekhova, & Posikera, 1999), and the 3- to 5-Hz range in infants shows functional similarity to the adult theta rhythm (Orekhova, Stroganova, & Posikera, 1999).

Outside the large literature relating specific characteristics of the EEG in infants and young children to the diagnosis of neurological disorders such as epilepsy, clinical studies of the EEG in developmental populations have tended to focus on the evaluation of disorders in learning and attention in childhood. Although these studies typically examine an older age range than the sample considered in the present study, this literature is informative: The most consistent finding is that an excess of spectral power in low-frequency bands (i.e., delta or theta) and a deficit in power at higher frequencies (i.e., alpha or beta) are associated with disorders of learning and attention in children (Barry, Clarke, & Johnstone, 2003; Chabot, di Michele, Pritchep, & John, 2001). Two main models have been proposed for the significance of this “slowing” of the EEG signal (Barry et al., 2003). In the “maturational lag” hypothesis, an excess of low-frequency power in the EEG is seen as indexing a delay in CNS maturation that correlates with behavioral indices of developmental delay (Corning, Steffy, Anderson, & Bowers, 1986; Corning, Steffy, & Chaprin, 1982). The inference of maturational lag in the EEG is based on observations that the relative contribution of low frequencies to the EEG power spectrum decreases with age in typical development, and the contribution of higher frequencies increases (John et al., 1980; Matousek & Petersen, 1973; Corbin, Penuel, Bickford, & Reginald, 1955; Gibbs & Knott, 1949). A second model for the EEG patterns seen in developmental disorders of attention states that a lack of high-frequency power (e.g., beta) in the EEG indicates cortical hypoarousal (Mann, Lubar, Zimmerman, Miller, & Muenchen, 1992; Lubar, 1991). There is no real consensus on which of these models best explains the EEG data in learning disorders, although recent approaches have suggested that there may be subgroups of children showing one or the other type of EEG deficit (Clarke, Barry, McCarthy, & Selikowitz, 2001b).

Although a relatively large number of studies have examined EEG profiles in children with various learning and attention disorders, few studies have examined the influence of adverse early rearing conditions or sociocultural risk factors on the development of the EEG in children. The studies that have done so have generally reported higher EEG power at low frequencies to be associated with detrimental aspects of the child’s living environment. For example, the expected decrease of relative theta power with age was not found in a cross-sectional sample aged 7–12 years from marginal urban areas in Mexico (Harmony et al.,

1988). These environments were characterized by unhealthy sanitary conditions, improper nutrition, poor environmental conditions, and psychosocial and cultural factors producing inadequate sensory and language experience. In a similar Mexican sample, low socioeconomic status (defined on the basis of maternal education level or household income) was associated with larger relative delta power at occipital and temporal regions, and reduced relative alpha power in frontal and temporal areas (Harmony, Marosi, Diaz de Leon, Becker, & Fernandez, 1990). Raine et al. (2001) also observed effects of early experience on EEG development in a sample of Mauritian children who had participated in a specially designed preschool program at ages 3–5 years. When these children were assessed 6–8 years later, low-frequency EEG activity (delta and theta power) was reduced in those children who had participated in the preschool program compared with a matched control group who had not received the intervention. Taken together with the literature on EEG in learning disorders, these studies suggest that an excess of low-frequency power and a reduction in high-frequency power in the EEG may be a neurophysiological signature of deficits in CNS functioning across a range of disorders and contexts.

One issue that has not been fully resolved in the developmental EEG literature is the best metric for representation of band power data. For a given electrode site and frequency band, EEG band power can be represented as absolute power (AP) or as relative power (RP). RP is a measure of how much a particular frequency band contributes to the total electrical activity at a given scalp site, and is computed as the proportion of power in a specific frequency band at a given electrode site relative to the total power in the EEG power spectrum at that electrode site. There has been some debate concerning the relative merits of AP or RP for representing EEG data in the context of brain maturation (Somsen, van’t Klooster, van der Molen, van Leeuwen, & Licht, 1997). RP helps to minimize individual differences in the magnitude of AP, a large part of which is thought to result from interindividual variation in anatomical factors such as skull thickness. This is especially important in longitudinal studies of EEG development (e.g., Marshall et al., 2002; Gasser, Jennen-Steinmetz, Sroka, Verleger, & Mocks, 1988; Gasser, Verleger, Bacher, & Sroka, 1988). Because RP values are proportion scores, an increase in AP in one frequency band will affect RP values in other bands. Reporting AP values in addition to RP can therefore be helpful in isolating the specific changes that result in changes in RP. In addition, AP lends itself to the study of hemispheric asymmetries in band power through the use of paired comparisons such as repeated measures analyses or computation of difference scores between power at homologous sites in each hemisphere (Davidson, 1988). Because of the relative merits of both metrics, one approach in developmental EEG studies is to quantify

and analyze both AP and RP (Clarke, Barry, McCarthy, & Selikowitz, 2001a; Somsen et al., 1997), which was the approach used in the current analyses.

In the present study, we compare institutionalized and never-institutionalized infants and young children on measures of EEG AP and RP in three frequency bands: 3–5 Hz (theta), 6–9 Hz (alpha), and 10–18 Hz (beta). Based on the literature relating specific patterns of EEG frequency distribution to cognitive deficits, behavioral problems, environmental risk factors, and developmental delays, we predicted that we would find a higher proportion of EEG power at lower frequencies and a corresponding reduction in EEG power at higher frequencies in the institutionalized group, compared with the never-institutionalized group. We also planned to examine hemispheric asymmetries in the EEG signal, which have proved useful in the study of behavioral development in infancy and childhood (Segalowitz & Berge, 1995), particularly in the domains of individual differences in approach and withdrawal tendencies (e.g., Fox, Henderson, Rubin, Calkins, & Schmidt, 2001).

RESULTS

To examine group differences in EEG patterns, repeated measures analyses of variance (ANOVAs) were computed using AP or RP as the dependent variable. These pairs of ANOVAs were run separately for each frequency band: theta (3–5 Hz), alpha (6–9 Hz), and beta (10–18 Hz). For each ANOVA, the within-subjects factors were region (frontal, central, parietal, occipital, temporal) and hemisphere (left, right). Group was the between-subjects factor, the two groups being the institutionalized group (IG) and never-institutionalized group (NIG).

Mean power values at each electrode site for each of the three frequency bands are shown for each group in Figure 1 for AP and Figure 2 for RP, with separate plots for each hemisphere. *F* values and significance values for main effects and interactions for the within- and between-subjects factors in the ANOVAs are shown in Table 1. Where follow-up tests are presented, the alpha values used as the criteria for statistical significance have been reduced in line with the Bonferroni correction method.

Note that main effects of region are clear from Figures 1 and 2 and are not followed up in the text. In addition, interactions not involving group (i.e., Region \times Hemisphere) are not described below.

Theta (3–5 Hz) Absolute Power

There was no significant main effect of group for theta AP. There were significant main effects for region and hemisphere, and three interactions were significant: Region \times Group, Hemisphere \times Group, and Region \times Hemisphere \times Group.

Main Effect of Hemisphere

Across the whole sample, there was significantly higher theta AP power in the right hemisphere.

Region \times Group Interaction

Follow-up repeated measures ANOVAs within each region separately showed that compared with the NIG, the IG had higher theta AP at occipital electrode sites, $F(1,148) = 28.16, p < .001$. This pattern was reversed at temporal electrode sites, where the IG had lower theta AP, $F(1,148) = 20.23, p < .001$.

Hemisphere \times Group Interaction

Follow-up repeated measures ANOVAs for each group separately showed that the right-sided hemispheric asymmetry in theta AP across the whole sample was due to a strong right-sided asymmetry for the NIG, which had higher power in this band in the right hemisphere compared with the left, $F(1,45) = 14.45, p < .001$. In the IG alone, there was no significant hemispheric asymmetry in theta AP.

Region \times Hemisphere \times Group Interaction

Follow-up paired *t* tests within the NIG showed that this group had higher power at the right temporal electrode site (T8) compared with the left temporal electrode, T7: $t(45) = 5.00, p < .001$. Similar comparisons did not reveal any significant hemispheric asymmetries in any regions for the IG. A likely further contribution to this interaction term can be seen in Figure 1: The difference in theta AP between the IG and NIG in the occipital region was particularly strong at the left occipital site (O1), whereas the group difference at the temporal region was particularly strong at the right temporal site (T8).

Alpha (6–9 Hz) Absolute Power

There was a significant main effect of group for alpha AP, as well as a main effect of region. There were also significant interactions for Region \times Group and Region \times Hemisphere.

Main Effect of Group

The IG had significantly lower overall alpha AP compared with the NIG.

Region \times Group Interaction

Follow-up repeated measures ANOVAs within each region separately showed that compared with the NIG, the IG had lower alpha AP in the frontal,

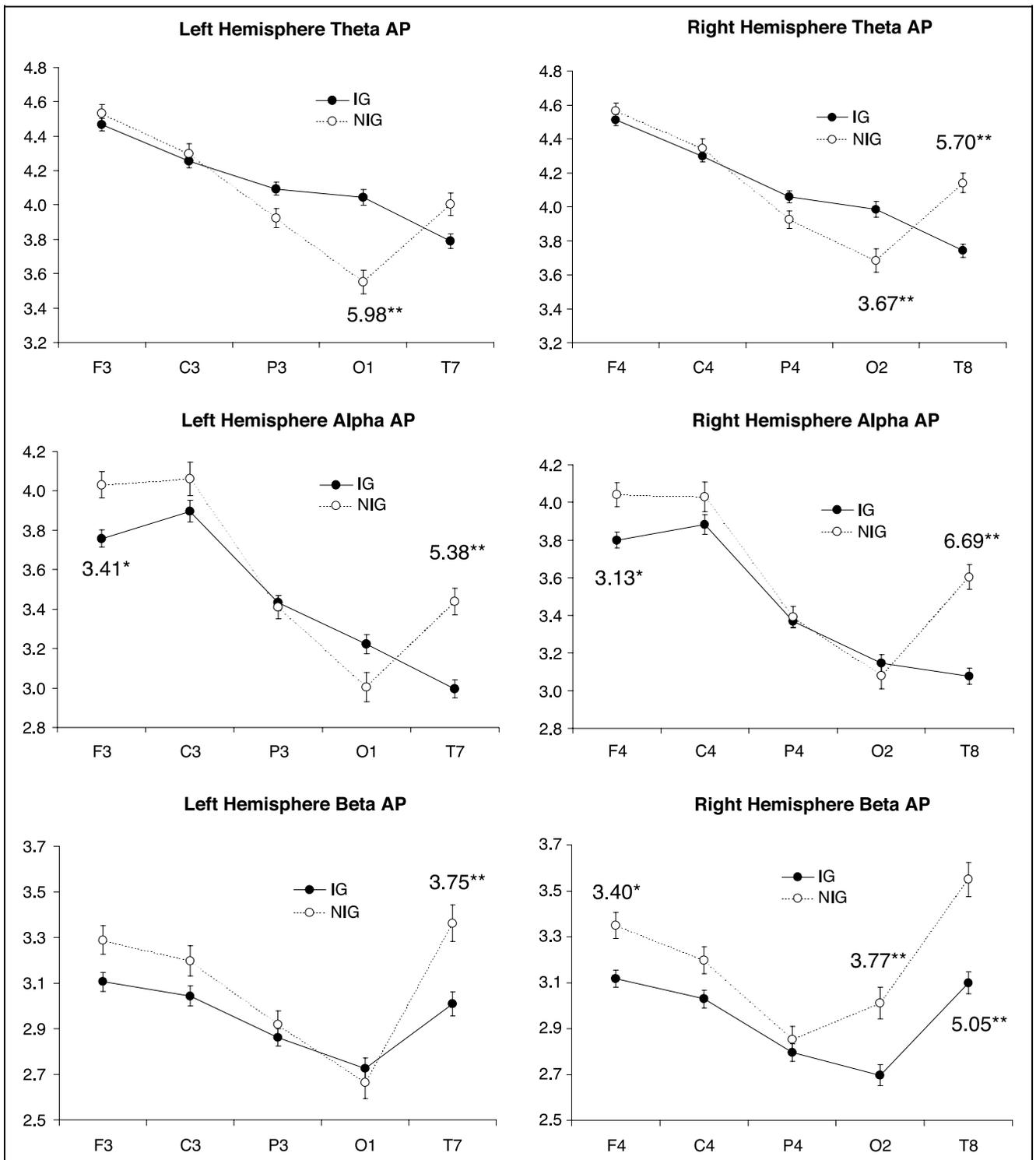


Figure 1. Mean absolute power values ($\ln \mu V^2$) for the institutionalized group (IG) and the never-institutionalized group (NIG) for the theta, alpha, and beta bands. Error bars indicate ± 1 standard error. Significant t statistics are shown using Bonferroni adjusted alpha levels ($*p < .01$, $**p < .001$).

$F(1,148) = 11.54$, $p < .001$, and temporal, $F(1,148) = 40.89$, $p < .001$, regions.

Beta (10–18 Hz) Absolute Power

There was a significant main effect of group for beta AP, along with significant main effects of region and hemi-

sphere. There were also significant interactions for every combination of factors.

Main Effect of Group

The IG showed significantly lower overall beta power compared with the NIG.

Main Effect of Hemisphere

Across the whole sample, beta AP was significantly higher in the right hemisphere compared with the left hemisphere.

Region × Group Interaction

Follow-up repeated measures ANOVAs within each region showed that the IG had lower beta AP than the NIG at frontal, $F(1,148) = 9.34, p < .01$, and temporal, $F(1,148) = 24.44, p < .001$, regions.

Hemisphere × Group Interaction

The right-sided asymmetry seen across the whole sample appears to be due to a strong asymmetry in band power for the NIG. A repeated measures ANOVA for the NIG alone showed that beta AP in this group was higher in the right hemisphere than in the left, $F(1,45) = 20.72, p < .001$. Within the IG, there was no significant hemispheric asymmetry in beta AP.

Region × Hemisphere × Group Interaction

As shown in Figure 1, the IG had significantly lower beta AP than the NIG at the right occipital electrode (O2) but not at the left occipital electrode (O1).

Theta (3–5 Hz) Relative Power

There was a significant main effect of group for theta RP, as well as a significant main effect of region. The Region × Group and Region × Hemisphere interactions were also significant.

Main Effect of Group

The IG had significantly higher overall theta RP compared with the NIG.

Region × Group Interaction

Individual repeated measures ANOVAs for each scalp region showed that the IG had higher theta RP than the NIG in the frontal, $F(1,148) = 9.62, p < .01$, parietal, $F(1,148) = 9.15, p < .01$, and occipital, $F(1,148) = 45.29, p < .001$, scalp regions. This interaction is also illustrated in the form of false-color topographic maps in Figure 3.

Alpha (6–9 Hz) Relative Power

There was a significant main effect of group for alpha RP. In addition, there were significant main effects of region and hemisphere, and significant interactions for Hemisphere × Group and Region × Hemisphere.

Main Effect of Group

Compared with the NIG, the IG had significantly lower overall alpha RP.

Main Effect of Hemisphere

Alpha RP was significantly higher in the left hemisphere compared to the right hemisphere.

Hemisphere × Group Interaction

The asymmetry in power across the whole sample appears to be due to a hemispheric asymmetry in band power for the NIG, which had lower alpha RP in the right hemisphere than the left, $F(1,45) = 10.08, p < .01$. There was no significant asymmetry for the IG.

Beta (10–18 Hz) Relative Power

There was a significant main effect of group for beta RP. There were significant main effects of region and hemisphere, and significant interactions for Region × Group and Region × Hemisphere.

Main Effect of Group

The IG had significantly lower overall beta RP compared with the NIG.

Main Effect of Hemisphere

There was significantly higher beta RP in the right hemisphere compared with the left hemisphere.

Region × Group Interaction

The IG had lower beta RP than the NIG over the occipital region, $F(1,148) = 34.80, p < .001$.

Effects of Sex, Height, Weight, and Head Circumference

Additional ANOVAs were run to test for main effects and interactions involving gender. When sex was used as an additional between-subjects factor in the above ANOVAs for AP and RP, it did not appear in any significant main effects or interactions.

Because variables reflecting differences in physical size are a possible confounding factor in the current analyses, the above ANOVAs for AP and RP in each of the three EEG frequency bands were rerun with height, weight, and head circumference as covariates. Physical data were unavailable for six participants (4 IG, 2 NIG). After controlling for these physical variables, significant main effects of group were preserved for alpha AP, $F(1,139) = 5.33, p < .05$, beta AP, $F(1,139) = 4.99, p <$

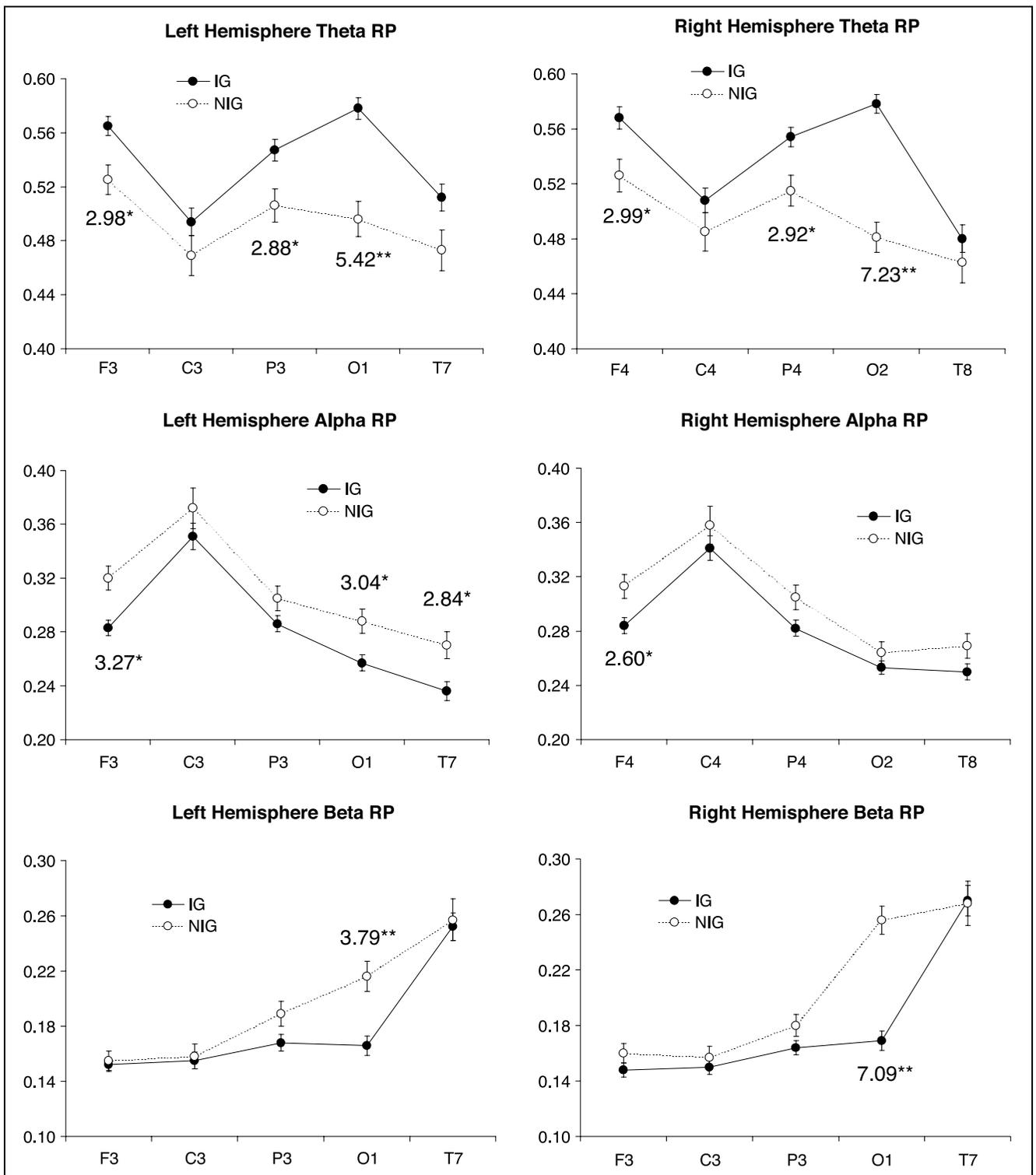


Figure 2. Mean relative power for the institutionalized group (IG) and the never-institutionalized group (NIG) for the theta, alpha, and beta bands. Error bars indicate ± 1 standard error. Significant t statistics are shown using Bonferroni adjusted alpha levels (* $p < .01$, ** $p < .001$).

.05, theta RP, $F(1,139) = 11.71$, $p < .01$, and alpha RP, $F(1,139) = 7.57$, $p < .01$. The main effect of group for beta RP no longer reached significance, $F(1,139) = 2.24$, $p = .14$.

DISCUSSION

Across the three EEG frequency bands and the two power metrics, there were a variety of main effects and interactions involving the IG and NIG. These can be

Table 1. *F* Values for Main Effects and Interactions from Repeated Measures ANOVA for Each Frequency Band

	<i>Group</i> <i>F</i> (1,148)	<i>Region</i> <i>F</i> (4,592)	<i>Region × Group</i> <i>F</i> (4,592)	<i>Hemisphere</i> <i>F</i> (1,148)	<i>Hemisphere</i> <i>× Group</i> <i>F</i> (1,148)	<i>Region × Hemisphere</i> <i>F</i> (4,592)	<i>Region × Hemisphere × Group</i> <i>F</i> (4,592)
<i>Absolute power</i>							
Theta	.266	199.23*** ε = .62	40.90*** ε = .62	5.65*	11.06**	1.10 ε = .74	3.97** ε = .74
Alpha	5.22*	265.99*** ε = .64	26.14*** ε = .64	1.69	3.06	5.66** ε = .75	1.95 ε = .75
Beta	9.66**	101.99*** ε = .74	9.30*** ε = .74	13.22***	13.95***	9.78*** ε = .71	6.28*** ε = .71
<i>Relative power</i>							
Theta	13.18***	43.77*** ε = .82	9.09*** ε = .82	.046	.096	6.82*** ε = .72	1.55 ε = .72
Alpha	6.00*	121.99*** ε = .74	.678 ε = .74	6.13*	5.21*	4.90** ε = .80	1.62 ε = .80
Beta	4.65*	133.02*** ε = .52	12.83*** ε = .52	5.87*	2.79	5.64** ε = .48	3.03 ε = .48

Significance levels and Greenhouse–Geisser epsilon (ε) correction factors are shown.

* $p < .05$; ** $p < .01$; *** $p < .001$.

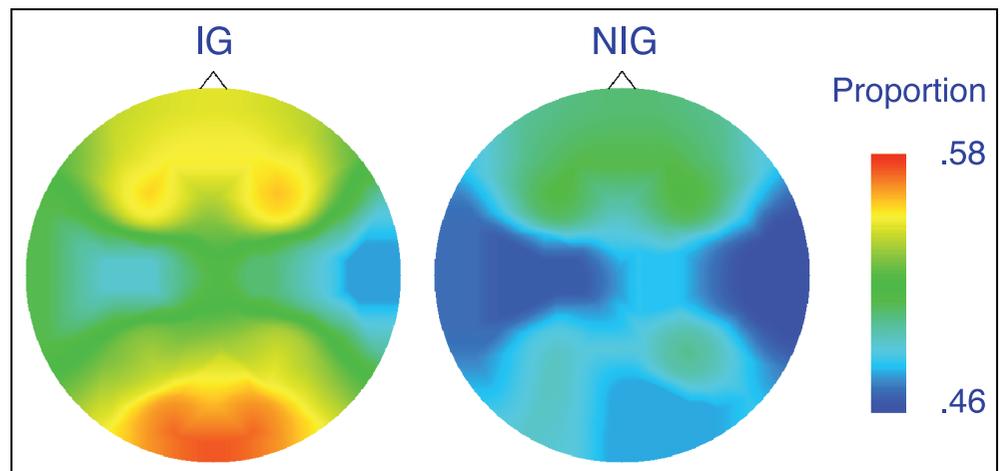
summarized as broadly reflecting the following: Group differences in the amount of AP, differences in the distribution of power within the power spectrum as indicated by the RP measures, and differences in hemispheric asymmetries in AP.

Given the association of an excess of low-frequency power and a deficit of high-frequency power with a variety of learning and behavior disorders in children and with exposure to adverse rearing environments, we hypothesized that this pattern would be seen in the IG. In agreement with this hypothesis, the IG had significantly higher theta (3–5 Hz) AP at occipital sites. In the

alpha and beta bands (6–9 and 10–18 Hz, respectively), the IG had significantly lower overall AP compared with the NIG, particularly at frontal and temporal electrode sites. The RP analyses showed that compared with the NIG, a greater proportion of spectral power for the IG was concentrated at lower frequencies: The IG had significantly higher theta RP than the NIG bilaterally at frontal, parietal, and occipital sites. These differences were accompanied by significantly less relative alpha power in the IG compared with the NIG.

In the literature examining electrophysiological correlates of childhood learning disorders, the most fre-

Figure 3. False-color topographic maps indicating the distribution of relative theta power across the scalp for the institutionalized group (IG) and the never-institutionalized group (NIG).



quently studied disorder has been the cluster of hyperactivity, inattention, and impulsivity, known as attention deficit hyperactivity disorder (ADHD). The most consistent finding in EEG studies of ADHD has been an increased level of relative theta power in children with ADHD compared with control children (for a review, see Barry et al., 2003). Reduced amounts of relative alpha and beta have also frequently been noted to occur in ADHD, with reductions in absolute alpha and beta power being found to a lesser extent. The results from the current study largely mirror these findings: As shown in Table 1 and Figures 2 and 3, the most prominent between-group difference was for RP in the theta band. In addition, significant group differences were also found for both AP and RP in the alpha and AP in the beta bands. A finding of reduced beta RP did not retain significance when body weight, height, and head circumference were used as covariates in the ANOVA.

The diagnostic specificity of increased relative theta and decreased alpha and beta power has not been established (Barry et al., 2003). Reduced alpha power has also been demonstrated in childhood autism, especially over frontal and temporal regions (Dawson, Klinger, Panagiotides, Lewy, & Castelloe, 1995), although the specific patterning of findings for other frequency bands in autism does not appear to be similar to the EEG profile in ADHD. However, there does appear to be a distinct similarity between EEG patterns in children with ADHD and children subject to poverty and other environmental risk factors (Harmony et al., 1990), which raises the possibility that excess relative theta power and reductions of alpha and beta power may be an electrophysiological signature of deviations in brain development common to a variety of disorders or contexts. In addition, many institutionalized or postinstitutionalized children exhibit attentional problems (Kreppner, O'Connor, & Rutter, 2001; Vorria, Rutter, Pickles, Wolkind, & Hobsbaum, 1998), but they also show a variety of other behavioral and cognitive deficits. There are several domains in which institutionalized children clearly differ from children in studies of ADHD, but given the commonality of the EEG pattern seen in ADHD and in the current analyses, the interpretation of the EEG findings in the ADHD literature is salient for the present study. As reviewed by Barry et al. (2003), two main models have been proposed as interpretations of the EEG findings in ADHD: (1) The maturational lag model proposes that there is a developmental lag in CNS development and functioning, with the emphasis being on excess relative theta activity as an indicator of delayed development of the EEG (Matsuura et al., 1993). (2) The cortical hypoarousal model (Satterfield, Cantwell, & Satterfield, 1974) states that children with certain EEG profiles are seeking stimulation due to a chronically low level of arousal, with this hypoarousal being reflected primarily

in reduced beta activity in the EEG (Lazzaro et al., 1999; Mann et al., 1992; Lubar, 1991). Neurophysiologically, there are a number of nonexclusive possibilities for the basis of either mechanism. Individual differences in patterns of synaptic strengths of intracortical axons on their target neurons may produce individual differences in the rate of change of EEG frequency composition with age (Nunez, 2000). Such differences would likely be a function of differences in neurotransmitter systems within the cortex, although it is not clear if one specific neuromodulatory system would be involved in producing an EEG profile with a relative excess of low-frequency activity. Another possibility relates to maturational changes in glial cells: Because myelination proceeds throughout childhood, between-group differences in the composition of the EEG power spectrum could be due to group differences in the rates of myelination within the cortex. A different mechanism proposed for an excess of relative low-frequency activity in the adult EEG is that GABA release in the nucleus reticularis thalami slows the dominant EEG rhythm and diminishes the transmission of sensory stimuli through the thalamus to the cortex (Hughes & John, 1999). In children, excess low-frequency EEG power in learning-disabled children has also been suggested to result from overactivation of the septohippocampal pathway as a result of reduced dopaminergic activity in the midbrain (Chabot et al., 2001).

In the ADHD literature, agreement has not been reached on which of the maturational lag and hypoactivation models best fits the EEG data, and both models have been criticized for certain shortcomings (Barry et al., 2003, 2004). It is also difficult to place emphasis on either maturational lag or hypoarousal as the best explanation for the EEG power spectral findings for the IG in the current study because this group shows interrelated patterns that could be accounted for by both models. Compared with the NIG, the IG had increased levels of relative theta activity, especially at posterior sites. In addition, the IG also showed significant reductions in AP in the alpha and beta bands, particularly at frontal and temporal scalp sites. The interrelation between these findings can be clarified by examining AP and RP in combination: The high relative theta power at certain scalp regions in the IG appears to be partly due to reduced levels of alpha and beta AP for this group. For instance, the IG and NIG did not differ on absolute theta power over the frontal region, but the NIG had significantly higher levels of relative theta power at frontal electrode sites. This seems to be because the IG had significantly reduced AP in the alpha and beta bands bilaterally over the frontal region. In this case, the lower RP in the alpha and beta bands results in a high level of theta RP because the total RP in the three bands at one site must sum to unity. However, the pattern appears to be different at occipital sites, where both absolute and

relative theta powers were higher in the IG. In addition, the IG had significantly lower theta AP at the right temporal electrode, although this difference was not reflected in a group difference in theta RP at temporal sites. These disparities may be partly explained by the fact that theta rhythms appear to have different functionality depending on scalp region. In infants, the magnitude of theta at frontal sites is increased by voluntary attention (Orekhova et al., 1999), whereas posterior and temporal theta rhythms are likely to have their own specific functional correlates. The current findings also strengthen the case for examining both AP and RP in developmental EEG studies because a consideration of both metrics can aid interpretation of group differences (Clarke et al., 2001a).

There were strong group differences in hemispheric asymmetry in AP, with the NIG showing overall right-sided asymmetries in theta and beta AP, whereas the IG showed no such overall asymmetry for any of the AP bands. The right-sided asymmetry in the NIG appears to be driven primarily by strong asymmetries in this group over the temporal region and, to a lesser extent, over the occipital region. Dawson et al. (1995) found reduced or reversed EEG asymmetries in autistic children relative to controls, although their findings were less region-specific than in the present study. It is notable that there were no apparent differences between the IG and the NIG involving EEG asymmetries over the frontal region. Specific patterns of frontal EEG asymmetry in absolute alpha power have been noted in infants of depressed mothers (e.g., Dawson, Frey, Panagiotides, Osterling, & Hessler, 1997) and have also been associated with approach and withdrawal tendencies to novelty in infants and children (e.g., Fox et al., 2001). Regarding the latter, there is a good deal of heterogeneity among institutionalized children in their reactions to novelty (Zeanah, Smyke, & Dumitrescu, 2002; Groza, Ilena, & Irwin, 1999), which may obscure group differences in this respect. In terms of the temporal and occipital asymmetries seen in the NIG, very few studies have addressed hemispheric EEG asymmetries in these regions over infancy and early childhood. A right-sided bias in EEG power has been noted in the occipital region from infancy through early childhood in a typically developing sample (Marshall, 2003), but there are virtually no studies of typical EEG development at temporal sites in this age range. However, there is neuroimaging evidence for asymmetries of the left and right temporal lobe in typically developing healthy populations of infants and young children (Matsuzawa et al., 2001; Utsunomiya, Takano, Okazaki, & Mitsudome, 1999; Giedd et al., 1996). In this sense, the lack of asymmetries in the EEG for the IG may be a further indicator of salient differences in the patterns of regional brain activity between institutionalized children and children living in more typical rearing environments.

METHODS

Sample

Participants in the study were 216 children aged between 5 and 31 months and their parents or institutional caregivers. The institutionalized group (IG) consisted of 144 children from six institutions within Bucharest. A pediatric screening had ensured that the IG was composed of children who were in fair health and who had no obvious genetic abnormalities or anthropomorphic signs of fetal alcohol syndrome. In subsequent assessments related to the longitudinal nature of the overall study (Zeanah et al., 2003), it became apparent that 11 children in the IG retrospectively failed to meet inclusion criteria because of emergent medical disorders, the symptoms of which were manifested some time after the initial screening. Data from these 11 children are excluded from further analysis in this article. The other 72 children composed the never-institutionalized group, which consisted of children matched to the IG on age and sex and who had been recruited using birth records. In the data set used for the current analyses, 9 children in the IG and 8 children in the NIG were not being seen in the longitudinal sequence of assessments outlined by Zeanah et al. (2003), but were seen in the laboratory for purposes of cross-sectional data collection.

Institutional Review Boards at the University of Maryland, the University of Minnesota, and Tulane University approved the study. The Institute for Maternal and Child Health in Romania and the local Commissions for Child Protection also approved the protocols. For all participants enrolled in the study, informed consent was obtained from biological parents, the Commission for Child Protection, or both. For full details of the recruitment of the groups and for other domains of assessment, see Zeanah et al. (2003). Included in the wider study were measures of height, weight, and head circumference for each child, which are used in the present study as covariates but are to be presented more fully elsewhere.

EEG Data Collection

The EEG was recorded from 12 scalp sites (F3, F4, Fz, C3, C4, P3, P4, Pz, O1, O2, T7, and T8) plus the left and right mastoids using a lycra Electro-Cap (Electro-Cap International, Eaton, OH) with sewn-in tin electrodes. An anterior midline site (AFz) served as the ground electrode, and the EEG was collected referenced to the vertex (Cz).

After the cap had been correctly fitted, the scalp underlying each electrode site was gently abraded before electrolytic conducting gel was inserted into the space between the scalp and the electrode. Impedances were measured at each electrode site and were considered acceptable if they were at or below 10 k Ω . All

channels were digitized at 512 Hz onto the hard drive of a PC using a 12-bit A/D converter (± 2.5 V input range) and Snap-Master acquisition software (HEM Data Corporation, Southfield, MI). One channel of vertical electrooculogram (EOG) was recorded using tin electrodes placed above and below the left eye to record blinks and other eye movement. The EEG and EOG signals were amplified by factors of 5000 and 2500, respectively, using custom bioelectric amplifiers from SA Instrumentation Company (San Diego, CA). Amplifier filter settings for all channels were 0.1 Hz (high pass) and 100 Hz (low pass). Prior to the recording of EEG from each participant, a 50- μ V 10-Hz signal was input into each of the channels and the amplified signal was recorded for calibration purposes.

During EEG collection, an experimenter placed a number of brightly colored balls in a bingo wheel and spun the wheel for a series of nine trials, each lasting 10 sec. This experimental protocol has proved very useful for EEG collection in awake infants and toddlers (e.g., Calkins, Fox, & Marshall, 1996). The spinning trials were separated by 10-sec intervals in which the experimenter stopped spinning the wheel and changed the number of balls in the wheel to maintain the participant's attention. The EEG signal was recorded for the entire 3-min period, but only data from epochs in which the wheel was being spun were subjected to further analysis.

All processing and analysis of the EEG signal was performed using the EEG Analysis System from James Long Company (Caroga Lake, NY). Epochs containing blinks or other eye movement were excluded from further analysis (Somsen & van Beek, 1998), as were epochs in which the EEG signal exceeded ± 250 μ V. The EEG channels were re-referenced in software to an average mastoids reference. The artifact-scored, re-referenced EEG data were spectrally analyzed using a discrete Fourier transform (DFT) with a 1-sec Hanning window having 50% overlap between adjacent windows. Spectral power (in μ V²) was computed in 1-Hz frequency bins centered on integer frequencies from 3 to 18 Hz for each of the electrode sites. Consistent with prior research in this age range (Marshall et al., 2002), power in the following frequency bands was then computed: theta (3–5 Hz), alpha (6–9 Hz), and beta (10–18 Hz).

Absolute power (AP) was computed by taking the natural logarithm of power in each frequency band. Relative power (RP) was computed as the proportion of power in each frequency band at a given electrode site relative to total power (3–18 Hz) at the same electrode site. Midline sites (Fz, Cz, Pz) were not considered in the current analyses, which focused on the left- and right-sided electrodes over the frontal (F3, F4), central (C3, C4), parietal (P3, P4), occipital (O1, O2), and temporal (T7, T8) scalp regions.

Participants for EEG Analyses

Across the entire sample, EEG data were collected for 186 participants (130 IG, 56 NIG). EEG data were not collected from 3 institutionalized participants and 14 never-institutionalized participants because of fussiness before or during placement of the EEG cap. In addition, the parents of 2 participants from the NIG declined to have EEG recorded from their child. In the current analyses, we focus on the 166 participants (117 IG, 49 NIG) with EEG data who were at least 9 months of age or older because EEG frequency bands are less well defined before 9 months of age (Marshall et al., 2002). Of these 166 participants, 13 (12 IG, 1 NIG) were excluded from further analyses because of problems with the EEG, including excessive noise in one or more channels, problems with the EOG signal, or other technical problems. Of the remaining 153 participants (105 IG, 48 NIG), 3 participants (1 IG, 2 NIG) had less than 30 artifact-free DFT windows and were excluded from further analyses. Final analyses are reported for $n = 104$ in the IG, and $n = 46$ in the NIG.

The mean number of artifact-free DFT windows across the 150 analyzed participants was 114 ($SD = 39$), with no significant difference between the IG ($M = 116$, $SD = 42$) and the NIG, $M = 110$, $SD = 33$; $t(148) = .97$, $p = .34$. The mean age for the IG was 22.4 months ($SD = 6.0$, $n = 104$), which was not significantly different from the mean age for the NIG, $M = 21.0$, $SD = 6.2$; $t(148) = 1.38$, $p = .17$.

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