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Atypical EEG Power Correlates With Indiscriminately Friendly Behavior in Internationally Adopted Children

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While effects of institutional care on behavioral development have been studied extensively, effects on neural systems underlying these socioemotional and attention deficits are only beginning to be examined. The current study assessed electroencephalogram (EEG) power in 18-month-old internationally adopted, postinstitutionalized children ($n = 37$) and comparison groups of nonadopted children ($n = 47$) and children internationally adopted from foster care ($n = 39$). For their age, postinstitutionalized children had an atypical EEG power distribution, with relative power concentrated in lower frequency bands compared with nonadopted children. Both internationally adopted groups had lower absolute alpha power than nonadopted children. EEG power was not related to growth at adoption or to global cognitive ability. Atypical EEG power distribution at 18 months predicted indiscriminate friendliness and poorer inhibitory control at 36 months. Both postinstitutionalized and foster care children were more likely than nonadopted children to exhibit indiscriminate friendliness. Results are consistent with a cortical hypoactivation model of the effects of early deprivation on neural development and provide initial evidence associating this atypical EEG pattern with indiscriminate friendliness. Outcomes observed in the foster care children raise questions about the specificity of institutional rearing as a risk factor and emphasize the need for broader consideration of the effects of early deprivation and disruptions in care.

Keywords: international adoption, institutionalization, EEG, indiscriminate friendliness, foster care

An early history of institutional care is associated with multiple degrees and types of adversity, which can range from prenatal risks (e.g., low birth weight) to postnatal malnutrition, medical problems, insufficient cognitive and social stimulation, and deprivation of consistent and responsive caregiver–child relationships (Gunnar, Bruce, & Grotevant, 2000; Johnson, 2000). Even in institutions that provide adequate physical and medical care, caregivers usually rotate frequently and there is typically a high infant to caregiver ratio (Lee, 2000; Vorria et al., 2003; Zeanah et al., 2003). Thus, at a minimum, institutionalized children are deprived of individualized attention and consistent social relatedness from a stable, responsive caregiver, a species-typical social experience that may play a role in neurodevelopment.

The first few years of life are a period of rapid neural development, and the institutional context may shape developing neural circuitry in lasting ways that then influence the child's functioning long after removal from the institutional environment, a process that some have described as experience-adaptive programming (Rutter, O'Connor, & the ERA Study Team, 2004). The brain may develop in ways that are adaptive within the adverse early rearing context, but due to limited plasticity these neural patterns may carry over to a new environment where they are no longer adaptive, such as an adoptive home (for a review, see Marshall & Kenney, 2009). A significant number of children are removed from institutional settings around the world early in life and adopted internationally. Their heterogeneous developmental outcomes following circumscribed periods of early institutional deprivation illustrate both the resilience and the vulnerability of the developing brain.

Behavioral Correlates of Institutional Rearing

Postinstitutionalized children typically demonstrate significant, often rapid gains across multiple developmental domains following adoption (Judge, 2004; Morison, Ames, & Chisholm, 1995;

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Van IJzendoorn & Juffer, 2006). However, those who have spent prolonged periods in institutional care early in life are at risk for enduring socioemotional and behavioral problems (Chisholm, 1998; Fisher, Ames, Chisholm, & Savoie, 1997; Groze & Ileana, 1996; Gunnar, Van Dulmen, & the International Adoption Project Team, 2007; Juffer & Van IJzendoorn, 2005; Judge, 2004; O'Connor, Bredenkamp, Rutter, & the ERA Study Team, 1999; Rutter et al., 2007; Van IJzendoorn & Juffer, 2006; Verhulst, Althaus, & Versluis-den Bieman, 1992; Zeanah et al., 2009). Indiscriminate friendliness—which is characterized by difficulty maintaining social boundaries and may include a lack of wariness toward strangers, a willingness to leave with a stranger, and a disinhibited tendency to socially engage strangers—is a disconcerting and persistent social problem observed in some postinstitutionalized children (Chisholm, 1998). High levels of indiscriminate friendliness were present in 69% of children assessed while they were still living in a Romanian institution (Zeanah, Smyke, & Dumitrescu, 2002).

In a significant minority of postinstitutionalized children, indiscriminately friendly behavior persists for many years after leaving the institution and being placed in a family (e.g., Bruce, Tarullo, & Gunnar, 2009; Chisholm, 1998; Hodges & Tizard, 1989; O'Connor et al., 1999; Rutter et al., 2004, 2007). Indeed, Rutter et al. (2007) recently reported that at age 11, about two fifths of Romanian postinstitutionalized children in the United Kingdom who had been adopted between 6 months and 4 years of age continued to exhibit symptoms of indiscriminate friendliness. While indiscriminate friendliness has been conceptualized as an attachment disorder, several studies suggest that it is unrelated to attachment status (Zeanah et al., 2002) and that it often persists even among those postinstitutionalized children who have formed a secure attachment with an adoptive parent (Marvin & O'Connor, 1999).

Emerging evidence suggests that difficulty regulating attention is associated with indiscriminate friendliness and other adverse socioemotional and behavioral outcomes in postinstitutionalized children. Postinstitutionalized children have a well-established vulnerability to long-term problems with attention regulation and inhibitory control (Gunnar et al., 2007; Hodges & Tizard, 1989; Hoksbergen, Ter Laak, Van Dijkum, Rijk, & Stoutjesdijk, 2003; Kadlec & Cermak, 2002; Kreppner et al., 2001; Lin, 2003; Roy, Rutter, & Pickles, 2000, 2004; Zeanah et al., 2009). Among children with a history of institutional rearing, those who are inattentive and hyperactive are more likely to demonstrate disinhibited social behaviors (Roy et al., 2004). Bruce et al. (2009) reported that indiscriminate friendliness correlated with poorer attention regulation and inhibitory control but not with attachment-related behaviors. Indiscriminate friendliness may reflect insensitivity to social cues, and children with poorer regulatory abilities may be more prone to miss social cues and engage in disinhibited behaviors that violate social boundaries.

Neural Correlates of Institutional Rearing

The persistence of socioemotional and attention deficits years after adoption suggests a role for early social experience in the development of neural circuitry relevant to socioemotional behavior regulation, attention regulation, and inhibitory control. However, while effects of institutional care on behavioral development have been studied extensively, effects on neural systems underlying these deficits are only beginning to be examined. Chugani et al. (2001) took a first step toward addressing this gap in the literature with their study of the neural metabolism of postinstitutionalized Romanian children. Using positron emission tomography, they observed significantly reduced glucose metabolism in prefrontal and temporal structures, areas of the brain implicated in emotion regulation, inhibitory control, and higher level attention processes. The same research group recently published a study documenting white matter structural abnormalities in postinstitutionalized Eastern European children (Eluvathingal et al., 2006). Diffusion tensor imaging tractography revealed that the white matter tract connecting anterior temporal and frontal regions was underdeveloped. Abnormalities of this pathway have been associated with executive function problems (Nakamura et al., 2005; Nestor et al., 2004), which is noteworthy in light of the behavior problems and high levels of impulsivity that characterized the postinstitutionalized group reported by Eluvathingal et al. (2006).

In a series of electrophysiological studies, researchers involved in the Bucharest Early Intervention Project assessed a large sample of young, currently institutionalized Romanian children (Marshall, Fox, & the Bucharest Early Intervention Project Core Group, 2004; Marshall, Reeb, Fox, Nelson, & Zeanah, 2008; Moulson, Fox, Zeanah, & Nelson, 2009; Moulson, Westerlund, Fox, Zeanah, & Nelson, 2009; Parker, Nelson, & the Bucharest Early Intervention Project Core Group, 2005). When presented with facial recognition (Moulson, Westerlund, et al., 2009) and facial emotion processing tasks (Moulson, Fox, et al., 2009; Parker et al., 2005), institutionalized children had smaller amplitudes in several components of the event-related potential (ERP) response, indicating pervasive cortical hypoactivation in response to faces (Moulson, Westerlund, et al., 2009).

Marshall et al. (2004) recorded baseline electroencephalogram (EEG) readings from the same institutionalized sample, who were between 5 and 31 months of age at assessment. The institutionalized children showed a greater concentration of EEG power in lower frequencies (theta) compared with Romanian children reared in their birth families. This difference in relative power distribution was widespread, occurring bilaterally in frontal, parietal, and occipital scalp regions. In family-reared, typically developing children, the relative concentration of power in low frequencies decreases with age, a developmental trend that may derive from normative neurodevelopmental changes such as neuronal growth and myelination (John et al., 1980; Marshall, Bar-Haim, & Fox, 2002; Matousek & Petersen, 1973). The power distribution in institutionalized children may signal either damage to or delay in normal brain development (Marshall et al., 2004). Power has different functional correlates depending on the frequency bands. Power in higher frequencies indicates faster processing and a more alert state. Thus, the concentration of power in lower frequencies for the institutionalized children can be interpreted as hypoactivation (Marshall et al., 2004). Given the normative developmental changes in power distributions, an excess of low-frequency power compared with age-matched nonadopted peers can also be seen as suggestive of delayed maturation.

The neurophysiological processes through which a dearth in environmental stimulation would lead to cortical hypoactivation have not been determined (Moulson, Fox, et al., 2009). However, there is little reason to expect that deficits in stimulation are limited to early institutional rearing. Indeed, several studies have reported that children in Central and South America who experienced extreme poverty and other psychosocial risk factors early in life had relative power concentrated in lower frequencies compared with middle class children (Harmony et al., 1988; Harmony, Marosi, Diaz de Leon, Becker, & Fernandez, 1990; Otero, 1994; Otero, 1997; Otero, Pliego-Rivero, Fernandez, & Ricardo, 2003). To assess further whether cortical hypoactivation is associated specifically with institutional rearing or extends to other populations that experience early deprivation and disruption in care, the current study includes a comparison group of children internationally adopted from foster care settings.

A randomly selected subset of the children from Marshall et al.'s (2004) sample were removed from the institutional environment and placed in therapeutic foster homes when they were between 7 and 33 months of age (mean 23 months; Marshall et al., 2008). Because this was a planned intervention, these foster homes had a number of qualities that were not necessarily present in the foster care experienced by the children in the current study. Specifically, the therapeutic foster parents in the Bucharest Early Intervention Program were trained to respond sensitively to the children, licensed, paid equitable salaries, and supported by frequent contact with social workers (Zeanah et al., 2003, 2006). In a follow-up at 42 months of age, the children who had been in foster care for at least 24 months showed a concentration of power in higher frequencies (specifically, relative alpha power) compared with children who were still institutionalized (Marshall et al., 2008), suggesting some mitigating effects of the foster care intervention on patterns of cortical hypoactivation. However, children who had been in foster care for less than 24 months did not differ from the currently institutionalized group (Marshall et al., 2008), indicating that the hypoactivation pattern persists for some time following removal from the institutional environment.

The hypoactivation pattern observed by Marshall et al. (2004) in institutionalized children mirrors the characteristic distribution seen in children with attention and behavior problems. The association of elevated relative theta power with attention problems is extensively documented, with a literature that spans more than 70 years (e.g., Jasper, Solomon, & Bradley, 1938; for a review, see Barry, Clarke, & Johnstone, 2003). This pattern is particularly pronounced in children who have symptoms of both hyperactive–impulsive behavior and inattention. A causal relationship between elevated theta power and attention problems has been suggested, such that attention-deficit/hyperactivity disorder (ADHD) results from cortical hypoactivation (e.g., Satterfield, Cantwell, & Satterfield, 1974). Some authors have referred to this model as the hypoarousal model (Barry, Clarke, & Johnstone, 2003). Atypical power distribution reliably differentiates children with attention problems from typically developing children (Barry et al., 2003; Chabot & Serfontein, 1996; Mann, Lubar, Zimmerman, Miller, & Muenchen, 1992). The persistence of an atypical power distribution for at least 2 years following removal from the institutional setting (Marshall et al., 2008) could suggest a neural basis for the enduring attention problems and behavior disturbances observed in some postinstitutionalized children.

If these neural abnormalities were to persist across development, that finding would lend support to the sensitive period model; indeed, it would suggest that there may be a sensitive period for the aspects of neural development underlying typical developmental changes in EEG power distribution, such that plasticity begins to decline within the first few years of life. Another potential explanation of the data is the maturational lag model, which has been proposed as one possibility to explain this pattern of atypical EEG power distribution, both in the ADHD literature (for a review, see Barry et al., 2003) and by Marshall et al. (2004) with regard to their institutionalized sample. The maturational lag model posits that an atypical power distribution does not reflect brain damage or a permanent deficit in functioning but rather a delay in the normal developmental progression to increased concentration of EEG power in higher frequencies. If this hypothesis is correct, electrophysiological abnormalities should fade over time. Evidence so far is mixed. A longitudinal study of impoverished children who were experiencing ongoing environmental deprivation found that abnormalities in frontal power distribution became less pronounced from the toddler years to age 6, although they remained significant (Otero et al., 2003). In typical development, ERP components show an age-related decrease in amplitude and latency from infancy to early childhood (Nelson & Luciana, 1998), but currently institutionalized children do not show this pattern (Parker et al., 2005). If the postinstitutionalized children in the current study do not show an atypical power distribution a few months after adoption, that tends to support a maturational lag model (although further studies assessing the same children both before and after adoption would be needed). If, on the other hand, the postinstitutionalized children do show the atypical power distribution, that could reflect either a longer maturational lag or a sensitive period. The maturational lag model is difficult to conclusively reject, as the rate of catch-up is not specified.

To further investigate the impact of early social deprivation on brain development, the aims of the current study were (a) to ascertain if the pattern of elevated relative theta power and lower absolute alpha power that has been observed in currently institutionalized children (Marshall et al., 2004) would extend to internationally adopted postinstitutionalized children and (b) to determine if EEG power distribution would predict the behavioral outcomes of indiscriminate friendliness and inhibitory control deficits. Baseline EEG was recorded from 18-month-old internationally adopted postinstitutionalized children, and relative and absolute power were assessed. It was expected that EEG power would be concentrated in lower frequency bands for the postinstitutionalized children compared with nonadopted children reared with their birth parents. Following the methods of prior developmental studies of EEG (Clarke, Barry, McCarthy, & Selikowitz, 2001; Marshall et al., 2004; Somsen, Van't Klooster, Van der Molen, Van Leeuwen, & Licht, 1997), both relative and absolute EEG power were assessed. Relative power, which quantifies the proportion of total power in a given frequency band, has the advantage of not being biased by individual anatomical factors that affect absolute power, such as skull thickness; however, absolute power can assist in the interpretation of observed relative power differences between groups (Marshall et al., 2004). An additional comparison group of children internationally adopted from foster care was included to help disentangle the effects of institutional rearing in particular from more general effects of abandonment and early care disruptions. At 36 months of age, children participated in a follow-up visit to assess indiscriminate friendliness and inhibitory control. Measures of growth at the time of adoption and nonverbal cognitive ability at 18 months were obtained to rule out malnutrition and global cognitive delays as third variables that could underlie an association between EEG power at 18 months and behavioral outcomes at 36 months. It was hypothesized that a concentration of EEG power in lower frequency bands at 18 months would predict greater indiscriminate friendliness and lower scores on inhibitory control at 36 months.

Method

Participants

The participants were 143 infants who were 18 to 20 months of age when first assessed, most of whom met criteria for one of three groups. Members of the nonadopted group (n = 47; 39 female) were born and raised in their families in the United States. The adopted groups differed in terms of age at adoption and time spent in institutional or family care (see Table 1). The postinstitutionalized group (n = 37; 33 female) had spent at least 75% of their lives prior to adoption in institutions and no more than 2 months in family-based care, and at the time of adoption were at least 10 months old and less than 18 months old; the foster care group (n = 39; 15 female) had spent at least 75% of their lives prior to adoption in a family-based setting (e.g., foster care or relative care) and no more than 2 months in institutional care, and at the time of adoption were less than 18 months old. Eight adopted children (six female) did not meet criteria for any of the groups because they had received a mix of family-based care and institutional care or because care history was unknown, so that neither type of care was known to account for 75% of their preadoption care history. Another 12 children (four female) had spent at least 75% of their lives prior to adoption in institutions and no more than 2 months in family based care but were excluded from the postinstitutionalized group because they were under 10 months old at the time of adoption. These 20 children were not included in analyses of group differences but were included in analyses of the total sample to more accurately reflect the diverse care histories of internationally adopted children. Four children (two postinstitutionalized, one foster care, one nonadopted) were later diagnosed with a medical problem related to prenatal development (e.g., fetal alcohol spectrum disorder) or a genetic abnormality. These four children were excluded from all analyses. All of the adopted children were born outside the United States and were adopted by families living in the Midwestern United States. The groups did not differ with regard to socioeconomic status, as indexed by maternal education. The majority of mothers participating in the study were college graduates.

The adopted groups differed in terms of country of origin (see Table 1) because at the time these children were born, their countries of origin generally had either a foster care system or an institutional system in place to care for wards of the state. As a result, as Table 1 shows, there was very little overlap in nationality across the adopted groups. Type of care was largely determined by which system the child's country of origin had in place rather than by any factors specific to the child. The postinstitutionalized and foster care groups also differed significantly from each other in age at adoption (see Table 1), because countries using foster care tend to have procedures in place that permit international adoption

Table 1
Adoption Group Characteristics

Characteristic	Postinstitutionalized[a] N = 37		Foster care[a] N = 39		Early-adopted postinstitutionalized N = 12		Combination of care type N = 8	
	n	%	n	%	n	%	n	(%)
Country								
China	26	70.3	5	12.8	0	0	1	12.5
Russia	7	19.4	0	0	1	8.3	0	0
Ukraine	2	5.4	0	0	0	0	0	0
Guatemala	1	2.7	5	12.8	0	0	1	12.5
Korea	0	0	27	69.2	0	0	3	37.5
Columbia	0	0	0	0	9	75.0	1	12.5
Ethiopia	0	0	0	0	1	8.3	1	12.5
Nepal	0	0	0	0	1	8.3	1	12.5
Unknown	1	2.7	2	5.1	0	0	0	0

Characteristic	Postinstitutionalized			Foster care			Early-adopted postinstitutionalized			Combination of care type		
	M	SD	Range	M	SD	Range	M	SD	Range	M	SD	Range
Age at adoption (in months)***	12.0_1	1.9	10–17	7.6_2	3.1	4–15	3.5_3	1.4	2–7	8.8_4	3.7	5–15
Months in institutional care***	11.5_1	1.7	10–16	0.5_2	0.5	0–1	3.5_3	1.4	2–7	3.8_3	2.0	2–8
Months in family care preadoption***	0.3_1	0.9	0–4	7.0_2	3.3	3–15	0_1	0	0–0	4.3_2	2.2	2–7
% female^{***b}		89.2_1			38.5_2			33.3_2			75.0_1	

Note. The numerical subscripts indicate which groups differed from one another within each variable. For instance, for Age at Adoption, all four groups differed (thus they each have a different number).
[a] These two groups were included in group analyses, along with the nonadopted group. Early-adopted postinstitutionalized and combination of care were excluded from group analyses due to small sample size but were included in analyses of the full sample to better represent the diverse care histories of adopted children. [b] The nonadopted group was 83.0% female and did not differ from the postinstitutionalized or combination of care groups in sex ratio.
*** $p < .001$.

when children are younger (Gunnar et al., 2000). Thus, age at adoption needed to be considered in the analyses. The nonadopted children were predominantly female, to approximate the gender ratio in the postinstitutionalized group. However, the foster care group did not have this gender ratio because every available and willing participant who met criteria for this group was included in the study.

Procedures

The children in the internationally adopted groups were recruited from a registry that included over 3,000 internationally adopted children. Children were included on the registry after their parents returned a postcard expressing a willingness to participate in research. Parents who adopted from two large adoption agencies that handle international adoption were sent a letter soliciting participation in this registry. The nonadopted children were recruited from a list of children whose parents indicated an interest in research, which was maintained by the university department through which the data were collected. Parents of all children born in the metropolitan area were solicited for this list through a mailing received soon after the child's birth. When children were 18–20 months of age, they participated in a laboratory session that lasted approximately 60 to 90 min. When children were 36–38 months of age, their parents were contacted and invited to bring the children back for a 90-min follow-up laboratory session. Both studies were approved by the university institutional review board, and parents gave informed consent prior to each study. Parents were present for the entire session and were advised that they were free to end the session at any time and to decline any aspect of the protocol. At each laboratory visit, parents were given a $5 gift card as a token of appreciation for their participation. Children received a small toy at the 18-month visit and a prize bag of small toys and stickers at the 36-month visit.

Measures

General deprivation. To assess the duration and degree of deprivation encountered prior to adoption, parents of the internationally adopted children completed a questionnaire during the 18-month laboratory session about their children's early care experiences. The length of time in any type of institutional care (e.g., hospital, baby home, orphanage) was used to index the duration of the institutional care. Two risk indices were created, following the methods of Bruce et al. (2009). Parents reported on prenatal risks they knew or suspected their child had experienced, including prenatal exposure to alcohol or drugs, prenatal malnourishment, and premature birth. These three prenatal risk factors correlated significantly and were summed to create a prenatal risk index (range 0–3). Similarly, parents reported on early care risks they knew or suspected their child had experienced, including physical abuse, physical neglect, social neglect, three or more living arrangements prior to adoption, and belonging to a minority group discriminated against in the child's country of origin. These five early care risk factors correlated significantly and were summed to create an early care risk index (possible range 0–5, actual range 0–3). These indices are imperfect measures, as they come from adoptive parents who may or may not have access to accurate information about their children's preadoption history.

As an additional indirect measure of general deprivation prior to adoption, parents reported their children's height, weight, and head circumference at their first postadoption doctor's visit. These growth measurements were indexed to World Health Organization (WHO) growth norms, yielding z scores for height, weight, and head circumference. For each measure, children one or more standard deviations below WHO norms were compared to the rest of the sample.

Electrophysiological recording. At the 18-month visit, EEG activity was recorded from 16 sites: frontal, central, temporal, parietal, and occipital scalp regions (fp1, fp2, fz, f3, f4, f7, f8, cz, c3, c4, t3, t4, p3, p4, o1, and o2). All sites were referenced to the vertex (cz) during data collection and later re-referenced to an average reference. Baseline EEG was recorded for 6 min while the child was seated in a high chair next to the parent. To keep the child quiet and focused with reduced motor activity, the experimenter blew bubbles, showed the child a rotating Ferris wheel toy, and performed silent puppet shows. The EEG was recorded by placing a stretch Lycra cap on the child's head that contained electrodes in the 10/20 placement system pattern. Small amounts of abrasive and conducting gels were inserted into the electrode sites of interest, and the blunt wooden end of a cotton swab was used to gently abrade the scalp. Electrode impedances were measured and accepted if below 5 kΩ. Additional abrading was sometimes necessary if impedances were above 5 kΩ. Amplifiers were set so that output of the signal was 50 μV peak to peak, with a gain of 10,000. The signal was digitized at 512 samples per second to prevent aliasing from affecting the data. Data were collected using the continuous recording mode of ERP-W software (ERP-W, n.d.), re-referenced to an average reference, and exported for analysis in EEG Analysis System software (James Long Co., Caroga Lake, NY). The EEG data were then scored for artifact due to eye movement or motor activity. Epochs containing amplitudes larger than 175 μV were considered to reflect motor artifact and eliminated from analysis. Eye blinks were identified in the fp1 channel, which is sensitive to eye movement, and these epochs were also eliminated from analysis. The data were analyzed with a discrete Fourier transform using a Hanning window of 1 s with a 50% overlap. The mean number of usable overlapping epochs was 348.66 (*SD* 151.74, range 85–689) out of a possible 720. Absolute power was computed for the 3–5 Hz (theta), 6–9 Hz (alpha), and 10–18 Hz (beta) bands and expressed in microvolts squared.

EEG data then were exported for statistical analysis. To normalize the distribution, a natural log (ln) transformation was used. Relative power in each band was computed for each electrode site as the ratio of the absolute power in that band to the sum of 3–5 Hz, 6–9 Hz, and 10–18 Hz absolute power. Mean relative and absolute power in each band was computed as the arithmetic mean of relative or absolute power in that band at each EEG collection site. EEG data were analyzed for 119 children (83.2%). Missing data were due to parental or child refusal of EEG collection, technical difficulties, or data that could not be analyzed due to excessive artifact. There were no group differences in the likelihood of having usable EEG data.

Nonverbal cognitive ability. At the 18-month visit, the Visual Reception subscale of the Mullen Scales of Early Learning (Mullen, 1995) was used to assess nonverbal cognitive ability (see Table 2). A nonverbal measure was selected so as not to be confounded by duration of exposure to the English language. The

Table 2
Descriptive Statistics for Behavioral Measures in the Postinstitutionalized, Foster Care, and Nonadopted Groups

Measure	Postinstitutionalized group			Foster care group			Nonadopted group		
	M	*SD*		*M*	*SD*		*M*	*SD*	
Mullen Visual Reception subscale *T* score at 18 months***	41.00_1	6.90		48.24_2	8.35		50.00_2	10.13	
Dinky toys									
Composite	−0.06	0.59		−0.17	0.67		0.14	0.86	
Latency to first transgression (seconds)*	10.71	8.07		9.19_1	9.41		15.62_2	10.53	
Frequency of transgressions	1.16	0.85		1.48	0.96		1.33	2.00	
% exhibiting worst transgression (grab)	38.90			34.47			38.23		
	M	*SD*	Range	*M*	*SD*	Range	*M*	*SD*	Range
Gift task									
Composite	0.10	0.83	−1.11–1.44	−0.18	0.87	−1.61–1.44	0.01	0.87	−1.24–1.44
Latency to first transgression (seconds)	21.61	23.04		20.50	22.64		19.78	22.95	
Frequency of transgressions	1.94	1.63		3.00	2.33		2.33	1.98	
% exhibiting worst transgression (turns body)	44.40			59.10			44.40		
	M	*SD*		*M*	*SD*		*M*	*SD*	
DSA task									
Number of boundary violations (personal questions/comments to stranger, initiates physical contact with stranger)*	0.54_1	1.21		0.42	0.83		0.00_2	0.00	
Latency to first verbal initiation to stranger (seconds)	191.15	193.75		211.25	186.56		224.57	182.36	
Frequency of verbal initiations to stranger (in first 5 mins)	8.23	8.85		4.78	6.28		5.54	8.09	

Note. Numerical subscripts indicate which groups differed from one another.
* $p < .05$. *** $p = .001$.

Mullen scale, which is widely used to screen for developmental difficulties (Bradley-Johnson, 2001), yields standardized *T* scores calculated from age-based norms.

Indiscriminately friendly behavior. At the 36-month visit, parent and child participated in an observational measure to assess children's tendency to engage in indiscriminately friendly behavior with unfamiliar adults (Bruce et al., 2009; adapted from Tizard & Rees, 1975). The child was provided with a picture book and the parent was seated on the opposite side of the room with some paperwork. An unfamiliar female adult (i.e., a stranger) then entered the room and introduced herself. The unfamiliar adult sat quietly in the corner of the room for 1 min before inviting the child to play with some toys. After providing the toys, the stranger sat quietly for 4 min. During this time, the stranger responded briefly to any initiations made by the child but did not act to maintain the interactions. After this period, the stranger invited the child to play with her and proceeded to engage with the child for 4 min in a more typical fashion. Each interaction was videotaped and coded by a trained coder. The coder was not informed of group membership, but the child's racial characteristics relative to their parents (all of whom were Caucasian) likely provided information about adoption status in some cases. Descriptive statistics for all variables from this task are shown in Table 2. Although coders recorded latency to the child's first verbal initiation and frequency of verbal initiations to the unfamiliar adult, these measures were not included in the indiscriminate friendliness measure due to concerns that they would tap the temperamental construct of behavioral inhibition and identify children who were simply temperamentally exuberant. Instead, we constructed the indiscriminate friendliness score on the basis of behaviors that were clearly developmentally inappropriate for this age group and tapped the underlying construct of violation of social boundaries. These behaviors included asking a personal question, making a personal comment, or initiating nonincidental physical contact, all of which reflect symptom criteria in the *Diagnostic and Statistical Manual of Mental Disorders* (4th ed., text rev.; *DSM–IV–TR*; American Psychiatric Association, 2000) for reactive attachment disorder, disinhibited type. As these behaviors were relatively low frequency, each child received a dichotomous score (0, 1) for whether they engaged in any indiscriminately friendly behaviors toward the unfamiliar adult, including asking a personal question, making a personal comment ($n = 6$), or initiating nonincidental physical contact ($n = 11$). This dichotomous score was the measure of indiscriminate friendliness used in subsequent analyses. It should be noted that among children who exhibited indiscriminately friendly behaviors, the number of incidences ranged from one to six. Interrater reliability was calculated on 20% of the videotapes. Cohen's kappa coefficients were 1.00 for indiscriminately friendly behaviors and .94 for verbal initiations.

Delay of gratification. Two delay of gratification tasks were included in the 36-month assessment: the dinky toys task and the gift task (Kochanska, Murray, & Coy, 1997). For the dinky toys task, the child was asked to select a toy from a box full of prizes by verbally indicating the selection without touching or pointing to the prize. The task was videotaped and coded for worst transgression (ranging from no transgression to pointing at, touching, or grabbing a toy), latency to first transgression, and frequency of transgressions. If there were no transgressions, the latency score was the total length of the task (60 s). The dinky toys task was presented three times during the session, and the codes were averaged across the three trials. For the gift task, the child was instructed not to peek while a prize was being wrapped. It, too, was coded for worst transgression (no transgression, peeking by turning head only, or peeking by turning body), latency to the first transgression, and frequency of transgressions (see Table 2). Interrater reliability between two trained coders was computed for 20% of the videotapes. Cohen's kappa coefficients ranged from .81 to .92. Latency, worst transgression, and frequency of transgression within each task were highly correlated ($r = .51–.85$, $p < .001$) and were standardized and averaged. The composite measures from the dinky toy and gift tasks were significantly correlated ($r = .35$, $p = .001$) and were averaged to yield one composite measure of delay of gratification.

Analysis Plan

Following the methods of Marshall et al. (2004), repeated-measures analyses of variance (ANOVA) were used to examine group differences in EEG absolute power and relative power. To parallel the Marshall et al. study, which compared currently institutionalized and nonadopted children, analyses compared the postinstitutionalized and nonadopted children. Wherever there were significant group differences, the foster care group was then added to the model to assess whether the group difference could be specifically attributed to a history of institutional rearing. Given the variable gender ratios across groups, gender was considered as a potential covariate. Children who did not have any usable EEG data were excluded from analyses. Missing data for individual EEG channels were imputed via the single-imputation method in SPSS, drawing on the covariance matrix of all available data. The percentage of data imputed for each channel was: fp1: 5.0%, fp2: 13.4%, fz: 1.7%, f3: 2.5%, f4: 1.7%, f7: 1.7%, f8: 1.7%, c3: 2.5%, c4: 2.5%, t3: 4.2%, t4: 3.4%, p3: 7.6%, p4: 4.2%, o1: 3.4%, o2: 5.9%. There were 100 children with EEG data who met criteria for a group (30 postinstitutionalized, 29 foster care, and 41 nonadopted children). A repeated-measures ANOVA with relative 3–5 Hz (theta) power as the dependent variable, hemisphere and region as the within-subjects factors, and group as the between-subjects factor was run to assess the primary hypothesis that relative theta power would be elevated in the postinstitutionalized group. To assess the specificity of this EEG difference and to aid in interpretation of this result, additional repeated-measures ANOVAs of absolute and relative power were run separately for each frequency band: 3–5 Hz (theta), 6–9 Hz (alpha), and 10–18 Hz (beta). The frequency bands were defined on the basis of guidelines established in research with typically developing infants of this age range (Marshall et al., 2002). For each ANOVA, group (postinstitutionalized vs. nonadopted) was the between-subjects factor, and the within-subject factors were hemisphere (left, right) and scalp region (frontal, central, parietal, occipital, temporal). Where there were group differences, the analysis was expanded to include the foster care group, with follow-up analyses employing Bonferroni corrections. Main effects of group and interactions of group with hemisphere and scalp region were examined. For EEG measures on which the postinstitutionalized children differed from nonadopted children, associations with general deprivation variables explored the influence of duration and severity of deprivation. Specifically, for all the adopted children (including those who did not meet criteria for any group), mean absolute or relative power was regressed on age at adoption and the prenatal and early care risk indices. For all the adopted children, t tests compared mean absolute or relative power in children one or more standard deviations below WHO means for height, weight, and head circumference with children who were average or above average on these growth measures. To assess whether EEG measures related to general cognitive ability, mean absolute and relative power were correlated with nonverbal cognitive ability (the Mullen Visual Reception subscale) for all children (including those who did not meet criteria for any group).

Group differences in indiscriminately friendly behavior and delay of gratification were examined using chi-square and t tests. For all children, repeated-measures ANOVAs were conducted in each band with the absolute and relative power measures that showed significant group differences at 18 months as the dependent variables, hemisphere and region as the within-subjects factors, and indiscriminately friendly behavior (presence vs. absence) as the between-subjects factor. Similarly, for all children, repeated-measures ANOVAs of these same absolute and relative power measures were conducted with a median split of delay of gratification as the between-subjects factor. Associations of indiscriminately friendly behavior with general deprivation variables and nonverbal cognitive ability also were examined for all children.

Results

Gender

For the total sample, there were no gender differences in mean absolute or relative EEG power in any frequency band, in the prenatal or early care risk indices, or on any of the behavioral measures. Thus, gender was not included as a covariate in subsequent analyses.

Group Differences in Absolute and Relative Power

Descriptive data for mean EEG power by group and frequency are shown in Table 3.

Relative theta power. There was a main effect for group in the repeated-measures ANOVA for relative theta power, $F(1, 69) = 5.14$, $p < .05$, partial $\eta^2 = .069$, with the postinstitutionalized children having higher relative theta power than the nonadopted children. When the foster care children were added to the analysis, the main effect for group remained significant, $F(2, 97) = 3.33$, $p < .05$, partial $\eta^2 = .064$, but Bonferroni follow-up analyses indicated that only the postinstitutionalized and nonadopted children differed significantly from each other, with the mean relative theta power for the foster care children intermediate

Table 3
Mean Relative and Absolute Power by Frequency Band in the Postinstitutionalized, Foster Care, and Nonadopted Groups at 18 Months of Age

	Postinstitutionalized group $n = 30$		Foster care group $n = 29$		Nonadopted group $n = 41$	
Measure	*M*	*SD*	*M*	*SD*	*M*	*SD*
Relative theta	0.442	0.050	0.437	0.032	0.422	0.027
Relative alpha	0.340	0.023	0.345	0.019	0.349	0.020
Relative beta	0.215	0.051	0.216	0.032	0.225	0.025
Absolute theta	3.94	0.59	3.81	0.40	4.05	0.33
Absolute alpha*	3.13_1	0.63	3.06_1	0.50	3.40_2	0.43
Absolute beta	2.08	0.66	1.97	0.51	2.23	0.33

Note. Relative power is expressed as a proportion of total power. Absolute power is expressed in μV^2. The numerical subscripts indicate which groups differed from one another in absolute alpha power.
* $p < .05$.

to the other two groups. There were no significant interactions of hemisphere or scalp region with group. The means by group for relative theta power are depicted in Figure 1.

Absolute theta power. There were no group differences in absolute theta power, $F(1, 69) = 0.94$, *ns*, and no significant interactions.

Relative alpha power. There were no group differences in relative alpha power, $F(1, 69) = 2.86$, *ns*. Within-subjects contrasts with Greenhouse-Geisser correction did reveal a significant Hemisphere × Scalp Region × Group interaction, $F(2.67, 184.48) = 2.98$, $p < .05$, partial $\eta^2 = .041$, which persisted when foster care children were added to the analysis. Follow-up analyses indicated that there was a significant Hemisphere × Scalp Region interaction in the nonadopted group only, $F(2.26, 90.41) = 5.82$, $p < .01$. ANOVAs conducted in each scalp region separately indicated that in the frontal region, there was greater relative alpha power in the left hemisphere for the nonadopted group, $F(2, 39) = 28.06$, $p < .001$. For the other regions, there was no hemispheric difference in relative alpha power.

Absolute alpha power. In the repeated-measures ANOVA for absolute alpha power, there was again a main effect for group, $F(1, 69) = 4.65$, $p < .05$, partial $\eta^2 = .063$, with the postinstitutionalized children having lower absolute alpha power than the nonadopted children. A within-subjects test with Greenhouse-Geisser correction indicated a Scalp Region × Group interaction, $F(2.59, 178.95) = 2.94$, $p < .05$, partial $\eta^2 = .041$. When the foster care children were included in the repeated-measures analysis of absolute alpha power, the main effect for group remained significant, $F(2, 97) = 4.36$, $p < .05$, partial $\eta^2 = .083$. Follow-up analysis with Bonferroni correction indicated that the foster care group was significantly lower in absolute alpha power than the nonadopted children. The Scalp Region × Group interaction per-

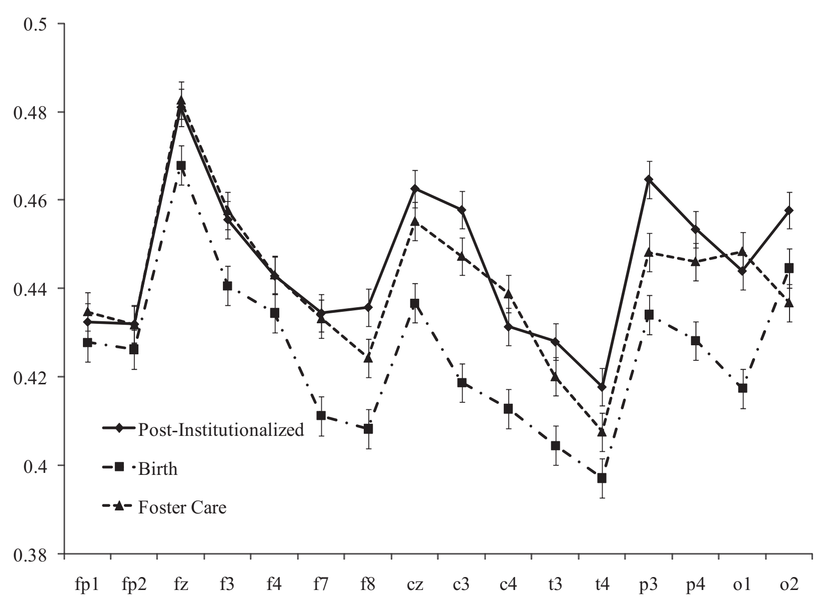

Figure 1. Relative theta power in the postinstitutionalized, foster care, and nonadopted groups. Frontal, central, temporal, parietal, and occipital electrode sites are on the *x* axis. The measure on the *y* axis is theta power as a proportion of the total power across all frequency bands.

sisted, $F(5.89, 285.43) = 3.15$, $p < .01$, partial $\eta^2 = .061$. Follow-up repeated-measures ANOVAs conducted within each scalp region separately indicated a significant group difference within the temporal scalp region, $F(4, 192) = 4.31$, $p < .01$, partial $\eta^2 = .082$, with Bonferroni tests showing that the nonadopted children had higher bilateral temporal alpha power than both the postinstitutionalized and foster care children. There was also a main effect of group for the central scalp region, $F(4, 192) = 6.65$, $p < .001$, partial $\eta^2 = .122$, with Bonferroni tests indicating that the nonadopted children had higher bilateral central power than the foster care children and higher left central power than the postinstitutionalized children. The parietal scalp region showed the same pattern, with a significant group difference, $F(4, 192) = 2.92$, $p < .05$, partial $\eta^2 = .057$, explained by the nonadopted children having higher bilateral parietal power than the foster care children and higher left parietal power than the postinstitutionalized children. There were no group differences in the frontal or occipital scalp regions in absolute alpha power. Figure 2 illustrates group differences in absolute alpha power.

Relative beta power. There was no main effect for group in relative beta power, $F(1, 69) = 1.23$, *ns*. Within-subjects contrasts with Greenhouse-Geisser correction did reveal a significant Scalp Region × Group interaction, $F(2.80, 193.35) = 2.95$, $p < .05$, partial $\eta^2 = .041$, which persisted when the foster care children were included in the analysis. To explore the Scalp Region × Group interaction, follow-up repeated-measures ANOVAs were conducted within each scalp region. There was a group difference in the central scalp region, $F(4, 192) = 3.44$, $p = .01$, partial $\eta^2 = .067$. In Bonferroni post hoc analyses, the nonadopted children had significantly higher left central relative beta power than postinstitutionalized children. There were no other regional group differences.

Absolute beta power. There was no main effect for group in absolute beta power, $F(1, 69) = 1.44$, *ns*. However, Greenhouse-Geisser-corrected within-subjects tests identified a significant Scalp Region × Group interaction for absolute beta power, $F(2.68, 184.92) = 3.70$, $p < .05$, partial $\eta^2 = .051$, which again persisted when foster care children were included in the analysis. Follow-up repeated-measures ANOVAs within each scalp region separately revealed a significant group difference in the central scalp region, $F(4, 192) = 5.32$, $p < .001$, partial $\eta^2 = .100$, which Bonferroni-corrected follow-up analyses indicated was due to greater bilateral central beta power in the nonadopted children compared with the foster care children. Similarly, the nonadopted children had greater bilateral parietal beta power than the foster care children, $F(4, 192) = 2.57$, $p < .05$, partial $\eta^2 = .051$. The nonadopted children had higher left temporal beta power than both the foster care and postinstitutionalized children, $F(4, 192) = 2.93$, $p < .05$, partial $\eta^2 = .058$. There were no group differences in the frontal or occipital scalp regions.

The pattern of results across frequency bands is summarized in Table 4.

General Deprivation and Relative Theta and Absolute Alpha Power

Mean relative theta power was regressed on age at adoption and the prenatal and early care risk indices. This model was not significant, $F(3, 70) = 0.07$, *ns*. This analysis was repeated for mean absolute alpha power, and again the model was not significant, $F(3, 70) = 0.08$, *ns*.

Being one or more standard deviations below WHO 2007 means for height, weight, or head circumference at first postadoption doctor's visit was not associated with relative theta power or with absolute alpha power. It should be noted that the adopted children were quite close to WHO growth norms at first postadoption doctor's visit: median z scores were −0.13 for weight, −0.12 for height, and 0.07 for head circumference.

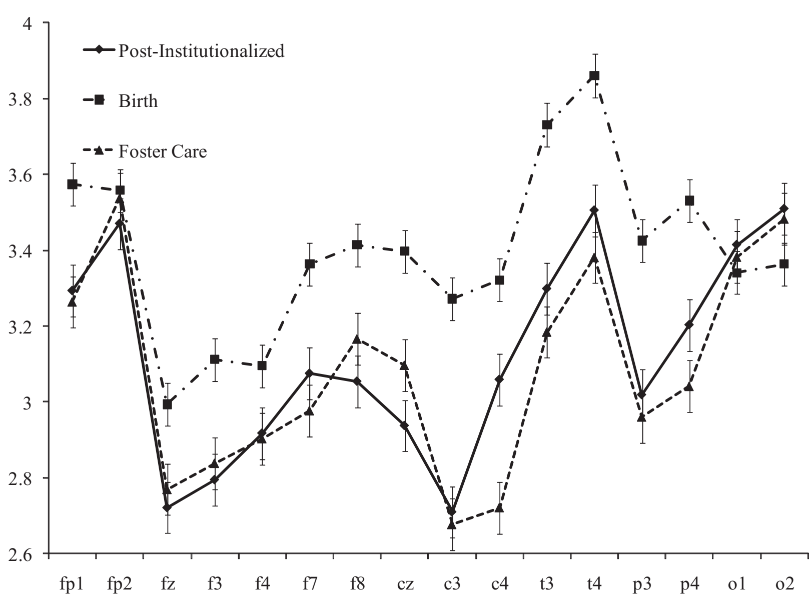

Figure 2. Absolute alpha power in the postinstitutionalized, foster care, and nonadopted groups. Frontal, central, temporal, parietal, and occipital electrode sites are on the x axis. The measure on the y axis is the log transformation of absolute alpha power in μV^2.

Table 4
Group Differences In EEG Power: Main Effects and Interactions

Measure	Main effect	Scalp region × Group	Scalp region × Hemisphere × Group
Relative theta	PI > NA		
Relative alpha			X
Relative beta		C3: NA > PI	
Absolute theta			
Absolute alpha	NA > PI, FC	C3: NA > PI, FC	
		C4: NA > FC	
		T3: NA > PI, FC	
		T4: NA > PI, FC	
		P3: NA > PI, FC	
		P4: NA > FC	
Absolute beta		C3: NA > FC	
		C4: NA > FC	
		T3: NA > PI, FC	
		P3: NA > FC	
		P4: NA > FC	

Note. PI = postinstitutionalized; FC = foster care; NA = nonadopted.

Nonverbal Cognitive Ability and Relative Theta and Absolute Alpha Power

Nonverbal cognitive ability at 18 months was not correlated with mean relative theta power or with mean absolute alpha power.

Group Differences in Indiscriminately Friendly Behavior

Foster care and postinstitutionalized children were more likely than nonadopted children to exhibit at least one instance of indiscriminately friendly behavior, $\chi^2(2, N = 85) = 7.96$, $p < .05$, Cramer's V = .306. Indiscriminately friendly behaviors were observed in 19.2% of the postinstitutionalized children (1–6 instances) and 20.8% of the foster care children (1–4 instances). None of the nonadopted children exhibited any indiscriminately friendly behaviors.

Although the groups did not differ in frequency or latency of verbal initiations, those of the internationally adopted children who exhibited indiscriminately friendly behavior also had more verbal initiations to the unfamiliar adult, $t(59) = 4.91$, $p < .001$, $r^2 = .290$, and had a shorter latency to first verbalization to the experimenter, $t(62) = 7.36$, $p < .001$, $r^2 = .466$.

General Deprivation and Indiscriminate Friendliness

Indiscriminate friendliness did not vary by age at adoption, nor was it related to the prenatal or early care risk indices. Children with a history of institutional care or foster care were equally likely to exhibit indiscriminately friendly behavior. Being one or more standard deviations below WHO 2007 means for height, weight, or head circumference at first postadoption doctor's visit did not predict indiscriminately friendly behavior at 36 months.

Nonverbal Cognitive Ability and Indiscriminate Friendliness

Indiscriminately friendly behavior was not predicted by 18-month nonverbal cognitive ability, $t(96) = 1.13$, *ns.*

Electrophysiological Correlates of Indiscriminate Friendliness

Repeated-measures ANOVAs examined EEG power in relation to indiscriminately friendly behavior. A dichotomous variable for indiscriminately friendly behavior (presence/absence) was the between-subjects factor, and the within-subjects factors were hemisphere and region. Indiscriminately friendly behavior at 36 months was predicted by higher relative theta power at 18 months, $F(1, 86) = 4.70$, $p < .05$, partial $\eta^2 = .052$. Indiscriminately friendly behavior also was associated with lower absolute power in the alpha band, $F(1, 86) = 6.71$, $p < .05$, partial $\eta^2 = .072$.

Delay of Gratification and Group

A one-way ANOVA found that there were no group differences on the *z*-scored composite delay of gratification variable, $F(4, 100) = 0.93$, *ns,* for the postinstitutionalized ($M = -0.03$), foster care ($M = -0.21$), and nonadopted ($M = 0.08$) groups.

Electrophysiological Correlates of Delay of Gratification

Repeated-measures ANOVAs examined EEG power in relation to inhibitory control. A median split of the composite delay of gratification variable was the between-subjects factor, and the within-subjects factors were hemisphere and region. Absolute alpha was not associated with delay of gratification. There was a nonsignificant trend for higher relative theta power to predict lower scores on the delay of gratification tasks, $F(1, 90) = 3.61$, $p = .06$, partial $\eta^2 = .039$. To explore the higher frequency power differences that might be underlying this trend, additional analyses were conducted with relative alpha and relative beta power. Relative alpha power was not related to delay of gratification. Higher relative beta power at 18 months predicted higher scores on the delay of gratification task at 36 months, $F(1, 90) = 4.34$, $p < .05$, partial $\eta^2 = .046$.

Discussion

EEG power distribution was assessed in internationally adopted postinstitutionalized 18-month-olds compared with age-matched nonadopted children and children internationally adopted from foster care. The association of this 18-month power distribution with indiscriminate friendliness and inhibitory control at 36 months was examined. As hypothesized, the postinstitutionalized children had a relative concentration of EEG power in lower frequency bands compared with the nonadopted children. That is, the postinstitutionalized children had higher relative theta power and lower absolute alpha power than the nonadopted children. This pattern of higher relative theta power and lower absolute alpha power was associated with indiscriminately friendly behavior at 36 months. The relative concentration of power in lower frequency bands also was linked to poorer inhibitory control on delay of gratification tasks at 36 months. Both internationally adopted groups were more likely than the nonadopted group to show indiscriminately friendly behavior. These results were not explained by measures of general deprivation or global cognitive ability. Each of these findings will be discussed, in turn.

Prior to this discussion, it is important to place the present sample of postinstitutionalized children within the broader framework of postinstitutionalized and institutionalized children whose brain activity patterns have been previously reported in the literature. The studies of neural development reviewed in the introduction included Eastern European children exclusively, often with an extended duration of institutionalization. The postinstitutionalized children in this study were adopted at 12 months of age on average, and all of them were 16 months or younger at adoption. They may be at lower risk than children adopted following more prolonged periods of institutional care (Nelson et al., 2007). The foster care children were even younger, averaging only 8 months of age at adoption. About 70% of the current postinstitutionalized sample was from China. Eastern European children placed in institutional care are known to be at elevated risk of prenatal alcohol exposure and low birth weight (Johnson, 2000), which are both risk factors for developing attention and behavior problems (e.g., Nanson & Hiscock, 1990). Prenatal alcohol exposure has been linked with EEG abnormalities in human infants (Chernick, Childiaeva, & Ioffe, 1983) and in animals (Cortese, Krahl, Berman, & Hannigan, 1997; Kaneko, Riley, & Ehlers, 1993). For Eastern European samples with a high risk of prenatal alcohol exposure, it is difficult to tell if neural abnormalities are due to prenatal experience, institutional rearing, or some combination. While children adopted from China also could have prenatal risks, this may be less common. In the current sample, prenatal alcohol exposure was suspected by half of the adoptive parents of children from Eastern Europe but by none of the adoptive parents of children from China. Shorter duration of deprivation, lower prenatal risk, and international diversity are strengths of the current sample because they permit characterization of the specific effects of a brief period of deprivation on early neural and behavioral development.

The excess of relative theta power observed in the postinstitutionalized children is consistent with the hypoactivation model that has been posited in previous studies of the effects of institutional rearing on neural development (Marshall et al., 2004; Moulson, Westerlund, et al., 2009; Parker et al., 2005). The generalization of this pattern consistent with hypoactivation to this relatively low risk sample strengthens the case that chronic neural hypoactivation may be associated broadly with a history of early deprivation, as opposed to reflecting some idiosyncrasy of the genetic characteristics or prenatal or postnatal experience of children reared in Eastern European institutions. The group differences in relative and absolute power strikingly parallel the group differences that Marshall et al. (2004) reported for currently institutionalized children compared with nonadopted children. The currently institutionalized children in their study and the postinstitutionalized children in this study both had higher relative theta power and lower absolute alpha power compared with nonadopted children. Electrical activity in higher frequency bands is associated with a more alert state and with faster and more active processing, so a relative reduction of power in these higher frequency bands suggests the brains of children with a history of deprivation and disruptions in care may be hypoactivated. This hypoactivation may persist for at least some period following adoption into a more stimulating environment.

The postinstitutionalized group had been with their families an average of 6 months, so EEG abnormalities persisted for at least 6 months following removal from the institutional rearing environment. This finding is consistent with Marshall et al.'s (2008) follow-up, in which it took 24 to 36 months after removal from the institutional setting for the atypical power distribution to begin to ameliorate compared with still-institutionalized children. The foster care group in the current study, who had been with their families for 10 months on average, were intermediate to the nonadopted and postinstitutionalized groups with regard to relative theta power, which may be consistent with a gradual shift in EEG patterns following adoption. It should be noted that the foster care group still had lower absolute alpha power than the nonadopted group. It appears that neural activation patterns have some capacity to adjust following early deprivation, but the course is a protracted one. As Marshall et al.'s follow-up did not include a never-institutionalized comparison group, it is not known if the group removed from institutional care had reached the point that they approximated the power distribution of never-institutionalized children or if there were constraints on this plasticity.

While the neurodevelopmental mechanisms underlying the links between early relational deprivation and an atypical power distribution are not yet known, it is possible that the lack of individualized attention from a stable, responsive caregiver delays or derails aspects of neural development. Drawing on evolutionary biology, Shonkoff (2010) has proposed a biodevelopmental framework in which the infant brain expects to develop in the context of certain species-typical environmental characteristics, including ample contingent social interaction with a stable caregiver, and that these experiences are necessary for brain architecture to develop normally (Shonkoff, 2010). EEG becomes concentrated in higher frequency bands with development, reflecting neurodevelopmental processes such as myelination (John et al., 1980). We speculate that for institutionalized children, the lack of social interaction with a primary caregiver may interfere with neurodevelopment, resulting in a relative excess of low frequency power. We further speculate that the partial amelioration of these EEG abnormalities following placement in foster care in Marshall et al.'s (2008) sample could be explained by the increase in one-on-one social interaction that the children experienced, which could have facilitated neurodevelopmental processes that were stalled or derailed while the children were institutionalized.

The current data do not allow differentiation between the maturational lag and sensitive period models. These models are incompatible, as the maturational lag model implies open-ended neural plasticity, whereas the sensitive period model specifies limited plasticity to adapt to the postadoption environment. Either model could fit with cortical hypoactivation in children with a history of institutional rearing: Hypoactivation could be temporary and likely to ameliorate following removal from the institutional environment, or it could be chronic and permanent. Following internationally adopted children over several years after adoption with repeated EEG measurements would allow examination of the developmental course of EEG power distributions. Even if cortical activation eventually rebounds to normal levels, one question to consider in future research is the developmental effect of having experienced an extended period of cortical hypoactivation. It is possible that the neural abnormalities underlying an atypical EEG power distribution might shape the developing child's brain and behavior in the early years of life in such a way as to contribute to enduring attention problems, even if the power distribution itself eventually returned to a developmentally typical pattern.

In the ADHD literature, a relative excess of low frequency power is associated with attention problems (Barry et al., 2003). The persistence of this same neural abnormality in postinstitutionalized children suggests a possible neural basis for the enduring attention problems often observed in these children. In the current study, children with less relative beta at 18 months had poorer inhibitory control at 36 months, and an excess of relative theta power at 18 months predicted the presence of indiscriminately friendly behaviors at 36 months. Thus, a relative excess of slow wave power was associated not only with attention deficits but also with indiscriminate friendliness. This finding provides initial evidence of neurodevelopmental correlates of a persistent socioemotional problem exhibited by some children with a history of early social deprivation. The association of indiscriminate friendliness with cortical hypoactivation, a neural pattern commonly observed in children with ADHD, tallies with reports associating indiscriminate friendliness with attention deficits in internationally adopted children (Bruce et al., 2009; Roy et al., 2004).

The prevalence of attention deficits in the current sample was unknown. Children are unlikely to be diagnosed with ADHD as early as 36 months, and attention regulation abilities are still developing at this age. On the one aspect of attention assessed in the current study, inhibitory control, the postinstitutionalized children did not differ from the nonadopted children. While disordered attention was not evident in this sample, which was low risk compared to previously studied postinstitutionalized samples, the association of hypoactivation with indiscriminate friendliness suggests pathways through which disinhibited social behaviors may become organized in development. The observed indiscriminately friendly behaviors were markedly developmentally inappropriate violations of social boundaries. For example, when the stranger entered the room for the first time, one child exclaimed, "I missed you!" Several children touched the stranger's knee or grabbed her hand. While indiscriminate friendliness was coded as present or absent due to its low incidence (occurring in about 20% of both internationally adopted groups), some children exhibited as many as three inappropriate personal questions or comments and three initiations of physical contact within the 10-min interaction.

Hypoactivation is not sufficient to result in indiscriminate friendliness. Children with ADHD and no history of early deprivation and disruptions in care typically are not described as exhibiting indiscriminately friendly behaviors. However, early deprivation and early disruptions in care appear to predispose children both to hypoactivation and to indiscriminate friendliness. Further research is needed to determine if cortical hypoactivation predicts individual differences in behavioral outcomes among children who have experienced adverse early care environments.

Accounting for the heterogeneity of outcomes in children who have experienced deprivation, neglect, and disruptions in care is a central challenge as the field moves forward. The measures of preadoption risk in the current study did not support the idea of a risk gradient or dose–response relationship to explain individual differences in relative and absolute power among the internationally adopted children. Parent report of early care risk factors and prenatal risk factors was unrelated to EEG, though this should not be taken as evidence that preadoption experiences are unimportant. The dearth of reliable information about children's preadoption histories is a problem endemic to research on internationally adopted children, and the current study is no exception. The children came from a variety of institutions and foster care homes in several countries, and direct measures of the quality of care in these settings were not available. Adoptive parent report was not based on first-hand observation, was likely incomplete, and could be colored by the parent's perception of the child's current functioning. Age at adoption and growth at adoption are more objective, though rough, estimates of exposure to deprivation, and these measures were not related to EEG power. However, the adopted children as a group were not growth delayed and were all adopted before 18 months of age. To determine if EEG power is related to malnourishment or duration of deprivation, a higher risk sample would be needed. Although the adopted children had lower nonverbal cognitive ability, this measure was unrelated to EEG power or to indiscriminate friendliness, suggesting that atypical power distribution and indiscriminate friendliness were not simply indicators of global developmental delays. Marshall et al. (2008) reported that EEG measures did not mediate the relation between age at placement and developmental quotient in their sample of postinstitutionalized children in foster care.

Progress in accounting for heterogeneity will depend both on acquiring more reliable and detailed information about the preadoption environment and on moving toward a consideration of genetic factors. Partnering with adoption agencies or individual institutions in the future may provide better estimates of the quality and characteristics of care in the preadoption environments. Work of this sort is beginning (Groark et al., 2005; Zeanah et al., 2003), though this will be challenging to put into practice. Obtaining measures of targeted genetic polymorphisms also will be challenging but potentially very useful. Genetics may play a role in individual differences in the vulnerability of the developing brain to adverse early care environments and the degree of neural plasticity in response to the postadoption environment (for example see Stevens et al., 2009).

To discriminate specific effects of institutional rearing from effects that would generalize to other forms of adversity, a comparison group of children internationally adopted from foster care was included. Like the postinstitutionalized children, the foster care children had experienced abandonment and early care disruptions, but they had spent little or no time in institutional settings. Although the foster care children did not differ from either of the other two groups in the relative power distribution, they had lower absolute alpha power than the nonadopted children. Indeed, the foster care children looked very similar to the postinstitutionalized children with regard to absolute alpha power, with both adopted groups having lower absolute alpha power than the nonadopted children in central, parietal, and temporal scalp regions. The presence of EEG abnormalities in the foster care children, who were adopted at an average of 8 months old, is a testament to the vulnerability of this developing system. Foster care children were just as likely as postinstitutionalized children to exhibit indiscriminately friendly behaviors at 36 months. Indiscriminate friendliness occurred in about one in five of the postinstitutionalized and foster care children; in contrast, none of the nonadopted children exhibited indiscriminately friendly behaviors. The presence of indiscriminate friendliness in both internationally adopted groups is consistent with the results Bruce et al. (2009) reported for 6- and 7-year-old children.

The prevalence of EEG abnormalities and indiscriminate friendliness in the foster care children indicates that these neural and behavioral deficits are not specific to institutional care histories but reflect a broad range of adverse early care experiences. Both groups experienced abandonment and relational disruptions in the early years of life. Little information is available as to the quality of foster care in the various countries, so it is possible that some of the children experienced deprivation or neglect while in foster care. If possible, it would be helpful to obtain better descriptive information about international foster care environments, though there are numerous barriers to this type of research. At a minimum, these children experienced relational disruption in the form of the loss of a stable primary caregiver, the foster parent, at the time of adoption. A pattern of EEG abnormalities quite similar to that seen in the postinstitutionalized and foster care groups has been observed in impoverished, high-risk Latin American children (Harmony et al., 1988, 1990; Otero, 1994, 1997; Otero et al., 2003), indicating that psychosocial deprivation can have developmental effects on EEG. Documenting indiscriminate friendliness in foster care children, Bruce et al. (2009) emphasized the importance of including comparison groups, such as children internationally adopted from foster care and maltreated/neglected children, in studies of postinstitutionalized children's behavioral development. The current findings underscore this recommendation and suggest the need for these comparison groups in studies of postinstitutionalized neural development as well. The resulting data would clarify whether all these children are simply on a continuum of deprivation, with corresponding effects on neural and behavioral development, or whether certain abnormalities may be specifically associated with the institutional rearing environment.

The current study has several limitations. As has already been noted, parents may not have been able to provide complete or reliable information about their children's preadoption experiences, so it was not possible to disentangle the influence of specific prenatal and early care factors on neural development. A low-density EEG array was used, which has limited spatial resolution. Use of a high-density array in future studies would allow for fine-grained analyses of regional patterns of EEG power. There was a predominance of girls in the postinstitutionalized sample, though there were no gender differences on any of the variables of interest. Finally, the children were too young for most measures of attention regulation at 36 months. Executive functions are only just beginning to emerge at 36 months, and they develop extensively throughout the preschool years and beyond (Diamond & Taylor, 1996). The current study did include delay of gratification tasks as age-appropriate measures of one aspect of attention regulation—inhibitory control—but a comprehensive assessment of multiple domains of attention regulation was not developmentally appropriate for this age group.

In sum, the findings from this study provide initial evidence that the relative excess of theta power that has been observed in currently institutionalized children persists in postinstitutionalized children several months after adoption and is not limited to children of Eastern European origin. This atypical power distribution, which is also characteristic of ADHD, predicted both indiscriminate friendliness and poor inhibitory control. These findings complement and extend previous research associating institutional rearing with neural abnormalities consistent with cortical hypoactivation. This study identifies longitudinal electrophysiological correlates of indiscriminate friendliness and suggests that the same pattern of hypoactivation underlies both poorer inhibitory control and indiscriminate friendliness, consistent with behavioral studies relating indiscriminate friendliness to attention regulation difficulties (Bruce et al., 2009; Roy et al., 2004). The deficit in high-frequency absolute power and the presence of indiscriminate friendliness in children internationally adopted from foster care hint that these neural and behavioral abnormalities are not limited to children reared in institutions but may also characterize other children with a history of relational deprivation. Replicating these findings and employing more specific neuroimaging methods will be critical to further characterize neurodevelopmental links between early relational deprivation and indiscriminate friendliness. It would be helpful to collect multiple electrophysiological and neuroimaging measures from the same sample, to see whether the various measures that have been interpreted as hypoactivation co-occur and whether they have shared behavioral correlates. It may be worthwhile to examine the EEG power distribution in other populations who have experienced disruptions of care, such as children in the U.S. foster care system. Although the current study raises more questions than it answers, results highlight the need for more research on the impact of institutionalization and other disruptions of care on developing neural systems and how those neural systems may in turn shape behavioral development.

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