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Getting the point: electrophysiological correlates of protodeclarative pointing

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Abstract

We examined the longitudinal relationships between power data in two bands (i.e. 4–6 and 6–9 Hz) of electrical activity in the brain at 14 months, as measured by background electroencephalograms (EEG), with protodeclarative and protoimperative pointing at 18 months, as measured by the Early Social Communication Scales (ESCS), [Mundy et al., ESCS: A Preliminary Manual for the Abridged Early Social Communication Scales, 1996, unpublished manual] ($n = 27$). EEGs were recorded from 64 sensors using the Electrical Geodesics (EGI) system's dense array sensor nets. Multivariate permutation testing (MPT), which controlled for experiment-wise error due to multiple significance tests, revealed significant correlations between log-transformed power in the frontal region at 14 months and protodeclarative, but not protoimperative, pointing at 18 months.

Keywords: Electroencephalogram; Multivariate permutation testing; Electrical geodesics; Protodeclarative; Protoimperative

1. Getting the point

1.1. *Electrophysiological correlates of protodeclarative pointing*

Communication becomes intentional in the second half of the first year of life and becomes linguistic in the second year of life for typically developing children (Fenson et al., 1994). Prelinguistic communication acts can be described by their overt forms (i.e. the observable behaviors used to communicate) and their pragmatic functions (i.e. the apparent reason the child communicated, Seibert et al., 1982). The two most common pragmatic functions observed during the first year are initiating behavior regulation (IBR) and initiating joint attention (IJA) (Wetherby et al., 1988). IBR is requesting or protesting the presence of an object or action (Wetherby et al., 1988). The most frequently studied behavior regulation act is requesting. IJA is sharing positive affect or interest in a referent or event (Wetherby et al., 1988). Pointing is an example of prelinguistic communication that makes the distinction between form and function clear. A child's point can be used declaratively to share her interests and experiences with others (i.e. IJA) or instrumentally to request an object or an action (i.e. IBR).

Children between 6 and 18 months show systematic, age-related gains in IJA and IBR but with considerable individual differences (Carpenter et al., 1998; Seibert et al., 1982). Individual differences in the use of prelinguistic pragmatic skills are important because they have demonstrated links to later cognitive, language, and social development (Carpenter et al., 1998; Corkum and Moore, 1998; Harris et al., 1996; McCathren et al., 1996; Mundy et al., 1990, 2000a,b; Ulvand and Smith, 1996) and co-vary with the presence or absence of particular disabilities (e.g. Dawson et al., 1998a,b).

In fact, the validity of the distinction between IJA and IBR is supported by the replicated finding that IJA tends to have different behavioral correlates compared to those for IBR. For example, IJA tends to be more frequently related to later language than does IBR (Mundy and Gomes, 1997, 1998; Mundy et al., 1988; Ulvand and Smith, 1996). IJA, but not IBR, distinguishes groups of children with autism from children with other disabilities who are matched on a variety of developmental measures (Baron-Cohen et al., 1992; Kasari et al., 1990; Mundy et al., 1995, 1986). In a study of 18-month olds, behavioral deficits in joint attention were key predictors of later diagnoses of autism in

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a sample of 91 typically developing and at risk toddlers (Baron-Cohen et al., 1992).

The distinction between IJA and IBR may be reflected in the developing brain's activation patterns, internal inherent rhythms, and electrical signatures. Unfortunately, IJA and IBR behaviors produce active motor movements, masking the neural activity that might distinguish the pragmatic intent of IJA and IBR functions. Consequently, researchers have used recorded neural activity during a passive, but awake, state.

Such background measures of neural activity are thought to quantify the child's predisposition to act or interpret sensory information in a particular way (Tomarken and Keener, 1998). Several studies have established relationships between positive affect or approach behaviors and background measures of neural activity (Calkins et al., 1996; Davidson and Fox, 1988, 1989; Fox and Davidson, 1987; Tomarken and Keener, 1998). For example, in a study of typically developing 4-year olds, children who displayed a high degree of social initiations and positive affect sharing exhibited greater relative left frontal activation. Children who displayed isolated, on-looking, and unoccupied behavior during the play session exhibited greater relative right frontal activation as measured by background electroencephalograms (EEG) (Fox et al., 1994).

One of the first studies that used a background neural imaging method (positron emission tomography, PET) to explore the link between early social communication and brain function was conducted with an epileptic population with a wide chronological age range, but an infant developmental level (Caplan et al., 1993). In this study, preoperative glucose metabolism in the left frontal regions positively predicted the children's postoperative IJA behaviors. There were no frontal lobe usage correlations with IBR and the frequency of IBR behaviors did not change after surgery. The use of PET with non-patient infant populations is limited because it requires the use of radioactive tracers. Another major form of neural imaging, functional magnetic resonance imaging (FMRI) requires immobilization of the head and most often requires sedation in infants and very young children.

EEG is a non-invasive imaging technique that is more comfortable and more available to non-patient populations of typically developing toddlers than either PET or FMRI. Through electrodes placed on the scalp, EEG records fluctuations in the electrical responses of neuronal ensembles. It measures the extracellular current flow, particularly the post-synaptic potentials, associated with the summed activity of many individual neurons. EEG provides a measure of neocortical dynamic function (Duffy, 1994; Nunez, 2000). Information regarding where on the scalp electrical activity is recorded, particularly from recently developed high-density arrays, offers better spatial resolution than EEG systems with relatively few electrodes. Background EEG is a record of neural activity when in a passive state. Studies with infants and young children often employ a visual stimulus as a calming influence (e.g. viewing bubbles floating over a black background or balls rotating in a bingo game's rotating chamber, Bell and Fox, 1992; Dawson et al., 1992; Mundy et al., 2000a,b).

Card et al. (1997) examined the relationships between EEG and measures of pre-linguistic communication in a longitudinal study of 23 toddlers studied from 14 to 18 months. Three minutes of background EEG, presumed to be the baseline activity of the neural system, was collected from six leads (F3, F4, C3, C4, P3, and P4). Analyses centered on log transformed power at each electrode for the frequency band 4–6 Hz. Card et al. (1997) reported that the frequency of behavior regulation acts were not significantly related to the frequency of joint attention behaviors. The researchers divided their sample into two groups, children who had increased numbers of total joint attention (TJA) acts (i.e. increase) and those whose TJA remained static (no increase) over the 4-month-period. Toddlers who increased in joint attention behaviors from 14 to 18 months exhibited less EEG power in the 4–6 Hz band from the left frontal electrode. The authors hypothesized that the 4–6 Hz band in infants is analogous to adult α activity (8–12 Hz). Evidence in adults suggests α activity represents "cortical idling" and is negatively related to cognitive processing (Pfurtscheller et al., 1996). Card et al. (1997) concluded that children who showed increases in IJA showed less α power, and therefore, were predisposed to more processing-related activation in the left frontal hemisphere than were children who did not show increases in IJA. No relationship between changes in behavior regulation acts and EEG α power was reported. It was not clear why the authors chose to dichotomize their dependent variable, which results in loss of information and consequent reduction in statistical power (Pedhazur, 1982).

Mundy et al. (2000a,b) examined the relationship between early social communication and EEG measures in 32, typically developing infants who were tested at 14 and 18 months. The 3 min of baseline EEG were collected from six electrode sites, F3, F4, C3, C4, P3, and P4. The frequency band 4–6 Hz was the focus. The frequency band of 6–9 Hz was included in this study, as well, but no significant findings were related in the report (Mundy et al., 2000a,b). A significant main effect for age ($F(2, 62) = 3.60$, $P < 0.04$), indicated that from 14 to 18 months, the toddlers demonstrated increased amounts of the combined pragmatic functions.

Hierarchical multiple regression analyses revealed significant and unique contributions of EEG measures to predicting prelinguistic pragmatics at 18 months. Unique positive predictors of IJA at 18 months included 14-month measures of IJA ($\beta = 0.61$, $P < 0.001$) and power in right central 4–6 Hz ($\beta = 0.73$, $P < 0.007$). Left frontal power in 4–6 Hz was a unique and significant negative predictor of 18-month IJA ($\beta = -0.68$, $P < 0.012$). There were no significant EEG correlates of IBR.

Previous studies of the association between EEG-recorded brain activity and pragmatic function use have several limitations. Firstly, most EEG studies have been collected with limited numbers (≤12) of electrode recording sites. Recently, advances in technology have made dense array systems with multiple electrode sites (>60) available. A dense array system for recording EEG offers a more spatially comprehensive view of the relationships between brain activity and behavioral measures of early social communication than the 12 or 6 lead systems used in the previous exploratory research. Secondly, pragmatic function was confounded with behavioral form. Therefore, it is possible that the different neurological correlates of the prelinguistic behaviors we label as IJA and IBR have more to do with differing overt behavioral forms, rather than differences in pragmatic functions. Therefore, it is important to study the EEG correlates of IJA versus IBR while controlling for behavioral form. Finally, because of the many sources of brain-imaging data in EEG, FMRI and PET studies, there is a high probability of spurious findings due to multiple significance tests. The problem of elevated experiment-wise error is potentially even greater in EEG studies that use high-density arrays because one way to analyze high-density array data is to use a significance test for every electrode. Therefore, it is important to examine associations between EEG measures and prelinguistic measures using statistical methods that control for experiment-wise error.

The most common way to control for experiment-wise error is to use Bonferroni corrections (i.e. use an α that is 0.05 divided by the number of significance tests). However, this approach is too conservative for EEG data (Blair and Karniski, 1994) and thus results in elevated probabilities of Type II error. This is particularly problematic when using the small sample sizes that are typical in EEG studies (Blair and Karniski, 1994). This over-correction occurs because the Bonferroni approach assumes that EEG information from electrodes are independent, when they are, in fact, highly intercorrelated (Blair and Karniski, 1994).

Multivariate permutation testing (MPT) is a well-suited method for controlling for experiment-wise error when predictors are highly intercorrelated (Ludbrook and Dudley, 1998; Westfall and Young, 1993). Permutation testing "provide multiplicity adjustments which automatically correct for all relevant correlational structures" (Westfall and Young, 1993, p. 112). Therefore, it has been specifically suggested for neuroimaging studies (Blair and Karniski, 1994). Blair and Karniski (1994) demonstrated empirically that permutation testing controlled for experiment-wise error, allowing the use of multiple testing at a standard α level of 0.05, with no loss of protection against Type 1 error due to multiple significance testing, even when predictors were highly intercorrelated. MPT is also less sensitive to outliers than other statistical techniques (Ludbrook and Dudley, 1998), making it particularly well suited for small sample analyses. Permutation testing requires that only two assumptions be met, that underlying distributions are symmetrical, and that alternative data points be simple shifts in value (Westfall and Young, 1993).

This research project examined the longitudinal relationships between patterns of brain electrical activity in typically developing 14-month-old children and observed IJA and IBR pointing at 18 months. We predicted that power in frontal areas and central areas at 14 months would correlate with the 18-month frequency of IJA pointing acts (PJA) and not with the frequency of IBR pointing (PBR) acts. Mundy et al. (2000a,b) hypothesized that infant α frequency occurs at 4–6 Hz, but 6–9 Hz has also been examined as a possible analog to adult α activity (Calkins et al., 1996). Therefore, this paper examined brain activity recorded in two frequency bands 4–6 and 6–9 Hz. This paper offers to advance the field in two ways: (a) differentiating form and function by focusing on the two distinguishable pragmatic functions of pointing: pointing to initiate joint attention and pointing to initiate behavioral regulation, and (b) using MPT to control for experiment-wise error. Both advances are likely to increase our confidence that our findings represent replicable ones.

2. Methods

2.1. Participants

Participants in the study were 39 typically developing 14-month-old infants. Participant visits were scheduled within 2 weeks either side of the 14-month birthday and 28 participants returned for a second visit within 2 weeks either side of the 18-month birthday. Ten did not return because we could not get enough artifact-free EEG data at time 1. One participant withdrew before the second visit. Participants were recruited through advertisements in the university newspaper, local parent magazines, posters in local infant retail shops, community centers and medical facilities. Calls to parents who had published birth announcements and local birth records for the relevant time frame were also used to recruit infants. Participants were offered US$ 25 per visit, a T-shirt, and a small toy for participation in the study.

Demographics describing the participants' chronological age, maternal education and mean scores on behavioral measures of interest are presented in Table 1. Recruiting was irrespective of gender, ethnicity or race. Thirty-seven of the participating children were caucasian; the other two were biracial. Children whose first language is not English were excluded, as their performance in one of the experimental procedures might be affected. One child had equal exposure to English and Spanish in the home. Parents were asked to confirm that their children were developing typically and were not premature. Ten children had incomplete EEG data and were not asked to return at 18 months. One of those who returned was excluded due to incomplete EEG data, bringing the number of participants included in the final data analysis to 27. Of those children included in the final analysis, 20 were female and 7 were male.

Table 1
Descriptors of the participants

Descriptor	Mean (S.D.)		
	Non-returning ($n = 11$)	Returning ($n = 28$)	Total sample ($n = 39$)
Chronological age at first visit (days)	427 (10.2)	428 (10.5)	428 (10.3)
Maternal education (years)	15.7 (1.19)	16.6 (2.2)	16.3 (1.96)
Paternal education (years)	15.3 (2.0)	16.0 (1.8)	15.8 (1.84)
Head circumference (mm)	472.7 (22.7)	475.2 (55.1)	474.5 (47.9)
Total IJA at 14 months	13.2 (6.5)	22.9 (9.7)[a]	20.2 (9.90)
Total IJA at 18 months		21.1 (8.92)	
PJA at 14 months	1.25 (.1.9)	2.26 (2.1)	2.0 (2.1)
PJA at 18 months		3.74 (3.5)	
Total IBR at 14 months	35.5 (13.7)	40.5 (14.5)	38.9 (14.3)
Total IBR at 18 months		42 (10.3)	
PBR at 14 months	6.8 (8.9)	5.6 (8.8)	6.0 (8.7)
PBR at 18 months		7.3 (8.5)	

[a] Indicates a significant difference between groups at the 0.05 level.

2.2. Overview of data collection sessions

Within 2 weeks either side of the subjects 14-month birthday, subjects were brought in for the first session. The participants were welcomed and informed consent was obtained in accordance with the University's Institutional Review Board Policies. During this time, research team members were introduced to the participants, and demographic, and handedness data were collected. The child's head was measured to determine which sensor net might produce the best fit. Then an experimenter began the videotaped Early Social Communication Scale (ESCS; Mundy et al., 1996). Research has shown that the ESCS yields valid and reliable measures of requesting, joint attention and social interaction behaviors in young, non-verbal children (Mundy and Gomes, 1998; Mundy et al., 1986, 1988). During the ESCS, the child was seated in the parent's lap across the table from the experimenter and a table of toys. This session generally took 20 min.

The participants were then shown to the EEG laboratory. This transition time was used to attend to child comfort issues and to explain the EEG procedure to the parent. Parents were asked to remain quiet during the recording and to use whatever means likely to keep the child quiet, without prompting undue noise or movement. The child sat in the parent's lap, and was distracted with toys, a puppet, and moving objects on a computer monitor while the sensor net was placed on the child's head. Once the cap was placed on the toddler's head, the tension of the net was adjusted to maximize sensor contact with the scalp. The room was darkened and the previous deliberate distractions ceased.

The child was then shown a colored circle that randomly stopped, started and moved about on a computer screen for, approximately 12 min, while the EEG recording was collected. Previous background EEG studies using distracters such as rotating bingo balls introduced random stimulus transients. The visual focus used in this study, mimics these distracters, while maintaining an exact record of when every experimentally induced transition occurred. When the complete recording was finished, or when the baby was unhappy enough to indicate dissent in the judgment of the parent and experimenters, post-recording impedances were recorded to further verify sensor contact quality and the cap was removed. Subjects received a toy and the US$ 25 reimbursement for time and travel.

Participants were asked to return for the 18-month visit if preliminary analyses of the EEG data indicated that at least 20 artifact-free segments had been successfully recorded. Returning participants returned to the Kennedy Center Laboratory for a 1.5 h visit within 2 weeks of their 18-month birthday. The 18-month-old toddlers either sat alone or on their parent's lap during the ESCS. The participants received a tee shirt and US$ 25 for participation.

2.3. EEG procedure description

Background EEG is considered a "valid marker of important aspects of brain maturation and integration that precede the emergence of skills" in infancy (Mundy et al., 2000a,b, p. 327). The measure derived from the EEG was power $(\mu V)^2$ in the 4–6 Hz (2.73–5.86 Hz) and 6–9 Hz (5.86–8.98 Hz) frequency bands. The EEG was recorded using the Electrical Geodesics (EGI) system using dense array geodesic sensor nets. Data from 64 active channels were collected and referenced to the channel at vertex (i.e. Cz). The sensors consist of electrolyte-soaked (KCl) sponges, which are in contact with the scalp and serve to conduct the electrical activity to silver/silver chloride (Ag/AgCl) pellets with in the base of the sponge. The Ag/AgCl pellets transduce the neurological signals and the electrical impulses are sent to high impedance (40 kΩ) 10,000 gain bioamplifiers. The signal was analog filtered by a 0.01–30 Hz Bessel filter. From the amplifiers, a National Instruments PCI 12 bit A–D board digitized the electrical information at a sampling rate of 200 Hz.

2.4. Variable derivation

2.4.1. Behavioral data

Videotapes of the ESCS experimental play sessions were copied, time-stamped, and coded for variables of interest. Reliability on the coding procedure was established after training and the 14-month sessions were coded first, checking reliability on one randomly selected subject for every five subjects coded (20% of the sessions). The 18-month sessions were coded separately and reliability was assessed similarly. Reliability results across categories were above 0.95 in both sessions and for all categories. Both coders examined disagreements until a shared decision was reached. The variables used in the analyses reported were the number of pointing gestures used to convey IJA and IBR. Pointing was defined as an extended index finger toward a referent, with or without eye contact with the experimenter. Initiating behavior regulation was defined as the child's request of an object or action if the toy was inactive. Initiating joint attention was defined as the child's pointing to a referent or event while the toy was active. The rationale for this distinction lies in the assumption that the child would not need to request an event that was already occurring, but would be indicating interest in the event itself. All other prelinguistic communication acts that were elicited were not included in these analyses because we focused on pointing for IJA and IBR functions to control for behavioral form/pragmatic function confounds. Duration of the session was not associated with frequency of use.

2.4.2. EEG data

After collection, data were segmented using EGI Netstation version 1 into 256 sample point (1280 ms) sized segments. Data for this analysis were from the portion during which the visual stimulus was moving smoothly to reduce the effects of stimulus transients. Data was calibrated for amplifiers' zeroes and gains, transformed to microvolt values, Hanning filtered and the absolute value of amplitude was calculated for each frequency (frequency resolution 0.78 Hz) for each of the 40 time segments of recorded EEG using FFTW Discrete Fourier Transform.

The observed distribution of absolute amplitude values was sorted within each channel. The mean absolute amplitude from the middle two quartiles of the distribution was calculated for each frequency for each EEG channel. Data across frequency amplitudes was averaged to determine values for frequency bands. These amplitude values (μV) were squared to derive power $(\mu V)^2$ values. Power for each subject was calculated for each channel.

This analysis focused on the 40 electrodes that were not closest or furthest from vertex (i.e. Cz; see Fig. 1). Electrical potentials generated by the brain passively move, or volume conduct, to the scalp where they may be recorded in an EEG. Voltage is the difference between two electrical potentials. Recordings made close together on the surface of a volume conductor will be more correlated and therefore, exhibit less voltage, than recordings made from sensors that are further apart. Since differences between more correlated values will be smaller than differences between

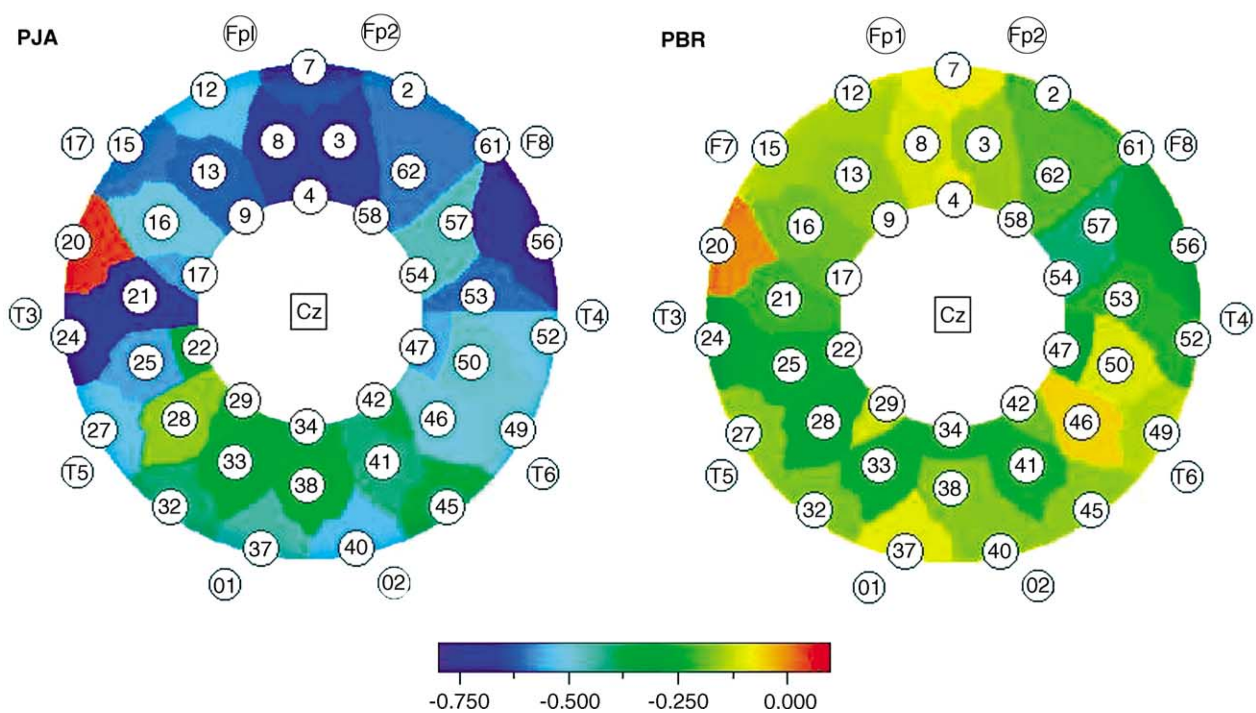

Fig. 1. Spatial map of *r*-values for correlations between EEG power at 14 months and pointing at 18 months in band 3.

less correlated values; voltages obtained for active sensors close to the reference electrode will tend to be smaller than voltages from sensors that are distant from the reference. This phenomenon is referred to as the polar distance effect (Junghofer et al., 2000). In order to help reduce the influence of the polar distance effect, the electrodes closest to reference and the electrodes that were furthest from reference (see Fig. 1) were excluded. In summary, the EEG variables were the power values at each of the 40 electrodes in the two selected frequency bands (i.e. 80 EEG variables).

2.5. Data analysis

Separate multivariate permutation tests were used to test predicted and exploratory associations for each pragmatic variable and set frequency band (i.e. four analyses for PJA and PBR in bands 2 and 3). This application of permutation testing required the following steps (Westfall and Young, 1993): (1) Analyze the problem and form a null hypothesis. The null hypothesis is that the relationship of interest is zero at all electrodes. The alternative is that a relationship different than zero exists at one or more electrodes (Ludbrook and Dudley, 1998). (2) Choose a test statistic that can discriminate between the hypothesis and the alternative. In this study, it was the absolute value of Pearson's r. The absolute value was used because we were testing for two-tailed significance. (3) Compute the absolute value of r for the association of the dependent variable (e.g. PJA) with the average power for each of the 40 electrodes. The observed absolute value of r is ranked and the label of the corresponding electrode is recorded. (4) Shuffle the values for PJA (or PBR) across subjects in such a way that the relationship between the criterion and EEG variables is broken. Compute the first set of resampled r-values. The resampled r-values show the relationship between the variables of interest (e.g. PJA) that could occur by chance. Rank the absolute value of the r-values from this shuffling of data from highest to lowest. The shuffle-compute-rank steps are repeated 10,000 times to form a probability distribution. Ten thousand repetitions offer a very accurate estimation of all possible combinations of the data (Blair and Karniski, 1994). (5) Determine the probability that the observed absolute r-value is observed by chance and accept or reject the null hypothesis. This is done by comparing the absolute value of the maximum observed r-value with the distribution of the 10,000 maximum r-values from the resampled associations. The number of resampled r-values higher than the observed r divided by 10,000 is the estimated P-value for the significance of the observed r-value. If the maximum r-value is significant, the computer programs deletes the data (original and resampled) that corresponds to channel that generated the significant observed r-value. For example, if average power from electrode 8 and PJA is found to produce the observed maximum absolute value of r, then the data from electrode 8 is deleted from both the observed and the resample data matrices for the subsequent steps of the analysis. Then steps 1–5 are repeated on the remaining data until the P-value is greater than α (i.e. 0.05 in this study using a two-tailed test).

3. Results

3.1. Preliminary data analysis

Means for the ESCS variables were compared between the group of children who returned, and who did not return at 18 months. As seen in Table 1, PBR and PJA at 14 months did not differ significantly in the two groups of children. Only total IJA, which includes pointing and non-pointing IJA, at 14 months was significantly different (F (1, 38) = 9.34, P = 0.004), with those returning exhibiting significantly more IJA than the group of children who did not return. No other information obtained about the children who did not return at 18 months distinguishes them from the group of children who returned.

Stability of the constructs, as reflected by significant relationships between the 14- and 18-month measures of the same variable, was examined. Neither of the two behavioral variables of interest, PJA and PBR, demonstrated a significant relationship from time 1 to 2. Therefore, it was not necessary to statistically control for time 1 PBR or PJA when examining the association between EEG measures and 18-month PBR and PJA. PJA exhibited a significant increase from 14 to 18 months ($t = -1.7$, $P = 0.046$) while the increase in PBR was not significant ($t = -0.68$, $P = 0.25$).

Similar to findings in Mundy et al. (2000a,b) and Bell and Fox (1992) for children of, approximately the same age, a 3–6 and 6–9 Hz frequency band could be distinguished in the EEG power. This finding supported our a priori decision to analyze the two frequency ranges previously identified in the literature, operationalized as band 2 (2.73–5.86 Hz as in Mundy et al., 2000a,b) and band 3 (5.86–8.98 Hz as in Bell and Fox, 1992; Fox and Davidson, 1987).

To render the r coefficient interpretable, EEG power variables were log transformed. The amplitude and number of the peaks per frequency interval for each channel was computed, the power in the 40 channels positively correlated with one another for all of the EEG variables (r-values ranged from 0.47 to 0.89). Child descriptors of handedness, gender, head circumference at 14 months, number of siblings, maternal or paternal education, chronological age in days at the time of EEG recording could not account for the primary associations of interest because they were not associated with power or pragmatic variables in this data set.

3.2. Primary data analyses of relationships between EEG and joint attention

3.2.1. Band 2

There were no significant correlations between the frequency of PBR at 18 months and power at 14 months. There were four significant, negative correlations with the

Table 2
EEG channels with significant correlations with PJA

Channel	Band 2		Band 3	
	r-value	*P*-value	*r*-value	*P*-value
2			−0.60	0.04
3	−0.58	0.04	−0.68	0.01
4	−0.61	0.02	−0.71	0.00
7	−0.55	0.05	−0.63	0.02
8	−0.62	0.02	−0.67	0.01
9			−0.62	0.03
13			−0.61	0.04
15			−0.60	0.04
21			−0.70	0.02
52			−0.69	0.02
53			−0.61	0.04
56			−0.77	0
57			−0.66	0.01
58			−0.78	0
62			−0.64	0.02

frequency of PJA at 18 months and the power at 14 months. The significant correlations presented in Table 2 are located in channels 3, 4, 7 and 8 with *r*-values ranging from −0.55 to −0.62. As seen in Fig. 1, these channels are located in the medial frontal area.

3.2.2. Band 3

There were no significant correlations between the frequency of PBR at 18 months and power at 14 months. There were 15 significant, negative correlations for the frequency of PJA at 18 months with the power at 14 months. The strength of the significant correlations, which range from −0.78 to −0.60, can be seen in Table 2. The location of these significant correlations can be seen in Fig. 1. Note that the majority of the channels with significant correlations are in the frontal area, with some extension into the central and right temporal areas of the brain.

4. Discussion

The aim of this investigation was to explore the relationships between toddlers' use of pointing for joint attention and pointing for behavior regulation with measures of brain activity in the frontal region. The study confirmed the hypothesized relationship between frontal activity and pointing for joint attention and provided new evidence that this association exists in both hemispheres of the frontal region.

The importance of frontal lobe activity in the development of initiating joint attention has been a consistent finding across physiological paradigms, including PET with a patient population (Caplan et al., 1993) and EEG with typically developing children (Card et al., 1997; Mundy et al., 2000a,b).

This study demonstrates that the longitudinal relationship between frontal power and initiating joint attention is attributable to the pragmatic function of the prelinguistic behavior, and not to the overt form of the behavior. That is, pointing 4 months later was related to brain activity in the frontal region only when pointing was used for initiating joint attention, not when used to regulate behavior. A unique attribute which differentiates IJA from other pragmatic functions is that the use of IJA typically results in a social response from the child's communicative partner that is not instrumental (i.e. it does not provide an activity or object to the child Mundy, 1995). Additionally, positive affect tends to occur more frequently during IJA than during IBR (Kasari et al., 1990; Yale et al., 2001). In fact, the definition of IJA requires that "interest or positive affect sharing about an object or event" be demonstrated. When one keeps these distinctions in mind and considers how IJA and IBR were measured in the ESCS, one point becomes clear. IJA is not obligatory at any point in the ESCS for sensory rewards to be present. In contrast, IBR is required for object spectacles to be repeated.

In contrast to IJA, a response by the child is obligatory in the task that is judged to elicit pointing for the function of behavior regulation (IBR). The stimulus has stopped moving and the child must request that it be activated in order to re-experience the reward value of the visual display. A social component is not associated with the visual reward obtained when the toy is reactivated following the child's point for behavior regulation. As such, IBR may more of a cognitive task than a social/emotional task.

Our first premise is that background EEG measures of activity in the frontal areas may reflect the extent to which children are rewarded by social interactions and thus are motivated to share interest and positive affect with others. Background EEGs have been posited to measure the predisposition of an individual to interpret and respond to stimuli in a particular manner, specifically along the continuum of approach and withdrawal (Mundy, 1995; Tomarken and Keener, 1998). Mundy (1995) posits the importance of this frontal approach system for the development of social cognitive skills. Social approach behaviors have been linked with left frontal EEG power in previous studies with infants and adults (Fox and Davidson, 1987; Kagan et al., 1988). Therefore, the results obtained in this study, suggest that children who demonstrate lower frontal power in band 3 at 14 months are those children who will subsequently be more likely to seek social rewards.

Our second premise is that the frontal region is special to predicting later IJA because of its role as one component of an integrated system which predisposes the child to find social interaction rewarding and to share positive affect. Rolls (1999) has proposed just such an integrated neural system of emotional/social response. Beginning with visual input from the environment, connections from the ventral visual pathway are linked to the amygdala, where the reward value or emotional significance of a stimulus is initially determined. Visual input then travels to the ventral medial prefrontal cortex (VMPFC), where the reward value of a stimulus is stored, and then to the anterior cingulate, where rewards for emotional and cognitive tasks are processed. The output of this integrated system is appropriate response selection by the basal ganglia based on the current motivational state of the organism.

It is also possible that the frontal activation observed in the current study represented activity of the anterior cingulate cortex. Recent studies have demonstrated that the rostral portion of the anterior cingulate gyrus is involved in processing of tasks which have an emotional component, while tasks which are cognitive in nature activate more posterior portions of the anterior cingulate (Bush et al., 2000). It is possible to regard the task that elicited behavior regulation to be a cognitive task in that the child is faced with solving the problem of how to reactivate the toy. In contrast, the task that elicited joint attention may be considered to have an affective component, as the child who uses an act of initiating joint attention is excited to share his visual experience with his communicative partner.

Enjoyment and interest appear to be the two most distinguishable aspects of positive affect. Enjoyment, as indicated by smiling, is more frequently exhibited in conjunction with IJA, rather than IBR behaviors, although, distinctions between IJA and IBR while controlling for behavioral form have not been reported. Links between positive affect and left frontal activation (Davidson and Fox, 1988), and positive affect and IJA (Mundy, 1995; Yale et al., 2001), seem to indicate that the tendency to share and seek positive affective interaction may support the relationship between EEG power and pointing for joint attention found in this study.

These same frontal areas have been shown to coincide with behavioral, affective and cognitive processing deficits in children with autism. Children with autism also have deficits in initiating joint attention (Dawson et al., 1998a,b). The underlying neural basis for these predispositions towards affect and approach may be related to dopaminergic afferents in the frontal and prefrontal cortex, particularly Brodmann's areas eight and nine and their connections to the anterior cingulate gyrus (Dawson et al., 1987; Dias et al., 1996; Tomarken and Keener, 1998). Failure of social stimuli to be represented in the VMPFC as either relevant or rewarding to the individual may also contribute to the behavioral differences characteristic of autism spectrum disorders. In summary, there are clearly missing parts to the full explanation for the empirical findings of this study. However, there is a confluence of information suggesting that background EEG of the frontal region may measure a predisposition to find social interaction reinforcing, which may in turn motivate the sharing of positive affect.

4.1. Limitations of this study

This study is limited by the general weakness of all correlational studies in that none of its findings can be interpreted as causal explanations. The study's generalizability is limited further by the small sample of convenience from which it is drawn. The infants in the study were children of well-educated mothers, and several levels of self-selection influenced the resulting sample. The total IJA at 14 months, which includes pointing and non-pointing JA, was significantly different, with those returning exhibiting significantly more IJA than the group of children who did not return. This difference in the light of the self-selection may be meaningful.

We recognize that our results do not support Mundy (1995) hypothesis of a special significance of the left frontal region in explaining variance in later initiating joint attention. Instead, the results of the present study indicate that power in band 3 is associated with later initiating joint attention in both right and left frontal regions. The explanation for the discrepancy between the present study and past findings is not presently known. However, it should be noted that this is the first study that controls for the form used to convey initiating joint attention versus other pragmatic functions. It is possible that difference is explanatory. One reason to expect power from both hemispheres of the frontal region to predict later pointing for initiating joint attention is that recent theories of the role of the prefrontal cortex emphasize the multiple connections between the various regions within the prefrontal cortex. This degree of connectedness makes inferences about the function of particular regions in the prefrontal cortex quite difficult (Miller and Cohen, 2001).

Additionally, the lack of relationship between 14- and 18-month IJA and IBR raises several questions. It may be that the functions are not being well differentiated (i.e. the pragmatic coding may not be a valid at 14 months) but are differentiated at 18 months. This could explain the difference in concurrent versus longitudinal correlations. However, many studies have shown that these IBR and IJA coding distinctions have predictable and differentiated behavioral correlates later supporting their early validity. Unfortunately, no past studies have controlled for form as we have done. A more probable explanation for the lack of association of the 14-month ESCS measures is that there was a restricted range in the 14-month data. Restricted ranges attenuate associations (Pedhazur, 1982). These limitations should be addressed through further replications with larger and more diverse samples with frequent measurement over extended longitudinal investigations to track the typical relationships of the measures in question.

4.2. Potential contributions

Several important points were verified in this study. Methodologically, there were two important contributions: this study provides further support for the use of background EEG as a measure of brain development, particularly in young children whose cooperation with response- or attention-required paradigms could be problematic. The use of MPT to identify particular locations from which power predicted PJA increases the probability that our findings are not sample specific. The replication of the link between activation in the frontal lobes and initiating joint attention should motivate further studies that seek to refine our understanding of these associations with increasingly focused hypotheses. The confirmation that the pragmatic function of pointing can be reliably differentiated in such a way as to produce longitudinal correlations with pointing for joint attention and not for behavior regulation is important to replicate. The importance of the frontal lobe, as demonstrated across studies, paradigms and populations, reinforces the central role this area of the brain plays in early communicative development. Also, this study reinforces the theoretical arguments of Fox and Byrnes (1998), Tomarken and Keener (1998), and Mundy et al. (2000a,b) on the importance of the background EEG as a measure of an individual's physiological predisposition to respond to stimuli and experiences.

Empirical findings suggest that EEG measures of frontal regions could be useful in understanding variance in the functioning of children with autism. For example, differences in frontal regions have been shown to coincide with behavioral, affective and cognitive processing deficits in children with autism. Children with autism also have deficits in initiating joint attention (Dawson et al., 1998a,b). The underlying neural basis for these predispositions towards affect and approach may lie in the previously identified monoaminergic afferents in the frontal and prefrontal cortex, particularly Brodmann's areas 8 and 9 and their connections to the anterior cingulate gyrus (Dawson et al., 1987; Dias et al., 1996; Tomarken and Keener, 1998). Differences in the reward value of social interactions, and the stored values may also contribute to the behavioral differences common to autism spectrum disorders.

In the future, research is needed to test the potential clinical utility of EEG measures in children with autism. For example, EEG measures could help special educators match children and interventions more efficiently. Children with developmental disabilities, including children with autism, show dysfunctional patterns of development in the areas of initiating joint attention and language development, which extend into widespread executive function disturbances as the children get older (Harris et al., 1996; Mundy et al., 1995, 1994). These children also develop language differently and have needs for intervention, which vary across children within categorical groupings. Adding an EEG component to the decision-making process regarding which children or groups of children are likely to respond successfully to particular interventions is a positive application of this line of research. For example, prelinguistic milieu teaching (PMT) is a behavioral treatment that has been successful in improving the communication of children with developmental disabilities without autism. However, it may not help all children with autism. Power in the frontal lobe in background EEG could predict which children are predisposed to approach and socially interact with the interventionist, helping to match children with the most potentially helpful intervention.

One of the authors (PJY) is currently testing the efficacy of two prelinguistic communication treatments focused on increasing IBR and IJA in prelinguistic children with autism. These two treatments are: (a) a variant of PMT (responsivity and PMT) and (b) picture exchange system (PECS). If our on-going research confirms our hypothesis that one of these two treatments will enhance children's ability to initiate joint attention, then our next step will be to determine whether background EEG measures predicts children's response to this treatment. Doing so will potentially improve our chances of matching particular children to treatments best suited to their needs.

An increased understanding of the brain–behavior relationships operating during development will continue to be a goal of collaborative teams of developmental, educational, physiological and cognitive researchers. Whether clinical consequences flow from the findings of this study rests largely in the hands of researchers who will replicate, extend, clarify and apply the information in future research. The scientific study of the development of mind, brain and behavior to support communication benefits from each additional piece of information.

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