Developmental Science 6:1 (2003), pp 48–54

REPORT

EEG coherence, joint attention and language development in the second year

Peter Mundy,[1] Nathan Fox[2] and Judith Card[2]

1. Department of Psychology, University of Miami, USA
2. University of Maryland, USA

Abstract

Recent research has raised the hypothesis that brain maturation processes may play an important role in the linkage between infant joint attention and language development. This hypothesis was examined using EEG, joint attention and parent report language measures in a longitudinal study of 29 infants assessed at 14, 18 and 24 months of age. The results indicated that both measures of joint attention and EEG coherence at 14 months were related to language development at 24 months. Furthermore, both EEG coherence measures and joint attention measures made contributions to multiple regression equations predicting individual differences in language development. Finally, coherence data from this study were consistent with Thatcher's (1994) theory of different patterns of neural integration and differentiation in the early maturation of the left and right hemispheres. The implications of these results for understanding the nature of the relations between joint attention and language development, as well as the utility of EEG coherence measures in developmental neuroscience are discussed.

Introduction

The acquisition of joint attention skills is thought to reflect a major milestone of infant development in the second year (Bakeman & Adamson, 1984) that is related to subsequent language, as well as cognitive development (Carpenter, Nagell & Tomasello, 1998; Mundy & Gomes, 1998; Tomasello, 1988; Ulvund & Smith, 1996). Yet, our understanding of the nature of the processes that link infant joint attention skills to language and cognitive development is incomplete. Seminal theory and research often emphasize the role of caregiving processes in delineating the factors involved in the association of joint attention with language development (Carpenter *et al.*, 1998). Several studies, however, have begun to reveal connections between joint attention skills and neural processes (Caplan, Chugani, Messa, Guthrie, Sigman, Traversay & Mundy, 1993; Kawashima, Sugiura, Kato, Nakamura, Natano, Ito, Fukuda, Kojima & Nakamura, 1999; Mundy, Card & Fox, 2000). These studies raise the hypothesis that some aspects of brain maturation may play an important role in the linkage between infant joint attention and language development.

In our own recent work, higher rates of glucose metabolism in the prefrontal cortex, especially the left frontal region, was observed to be a specific predictor of the tendency to initiate joint attention bids in a small sample of infants with intractable seizure disorder (Caplan *et al.*, 1993). Similarly, in a study of typically developing infants, Mundy *et al.* (2000) observed that the tendency to initiate joint attention episodes was associated with EEG indices of left-frontal activity. In particular, a robust association was observed between initiating joint attention bids at 18 months and an EEG coherence measure indicative of the differentiation of left-frontal and left-central activity during a baseline attention task at 14 months. This observation suggests it may be useful to consider EEG coherence measures in studies of the aspects of brain maturation that may be involved in the linkage between joint attention and language development.

EEG coherence is a measure of phase synchrony between spatially separated EEG generators. Theoretically it provides an index of aspects of neural network integrations and differentiations that are characteristic of CNS maturation (Thatcher, 1994). According to Thatcher (1994) changes in coherence across age in the left hemisphere may be reflected in a pattern of 'integration of differentiation', or a reduction in coherence among proximal cortical sites followed by an increase in more distant cortical coherence in baseline EEG. Alternatively, age

Address for correspondence: Peter Mundy, Department of Psychology, University of Miami, 5665 Ponce De Leon Blvd, Coral Gables, FL 33146, USA; e-mail: pmundy@miami.edu

changes in right hemisphere functions may be characterized by 'differentiation of integration', or a reduction of coherence between distal cortical sites, followed by an increase in coherence among more proximal cortical areas. These different types of left and right hemisphere coherence measures may be markers of neural organization and maturation processes that correspond to skill acquisition in different developmental domains (Bell & Fox, 1996; Fischer & Rose, 1994).

To the extent this is true, individual differences on measures of EEG coherence may be expected to be predictive of differences in cognitive and behavioral development. In particular, since joint attention is related to language development, and an index of left hemisphere coherence has been related to infant joint attention skills (Mundy *et al.*, 2000), a measure of this type of coherence may also be expected to relate to early aspects of language development. Furthermore, an examination of this hypothesis may be revealing with regard to the nature of the processes that link joint attention and language development.

A nativist and deterministic view leads to the expectation that the link between joint attention and language could be completely ascribed to brain maturation processes. In this case, EEG coherence measures may be expected to mediate any association between joint attention and language. Alternatively, a more transactional, self-organizing view of brain–behavior relations in the study of joint attention and language development (e.g. Baldwin, 1995; Bates, 1999; Mundy & Neal, 2001) suggests that joint attention behaviors may serve to organize information input to the developing child. Thus, although associated with brain maturation, joint attention behaviors themselves would also contribute to the information acquisition necessary for optimal language development (Baldwin, 1995), and perhaps even to subsequent brain organization and development itself (Mundy & Neal, 2001). This perspective leads to the expectation that related brain maturation and joint attention measures may both make unique contributions to language development. These alternatives were explored in this developmental follow-up of a longitudinal study first described in Mundy *et al.* (2000).

Methods

Participants

Thirty-two healthy, full term 14-month-olds (14 girls, 18 boys) participated in this longitudinal study. The toddlers were recruited from a major metropolitan area via mailing lists composed of parents with middle to upper-middle SES and a minimum education of graduation from high school. Ethnicity of the mothers was primarily Caucasian American (91%). Only toddlers born to two right-handed parents were recruited for this study. Three infants (9%) did not return for their 24-month follow-up visit reducing the final sample to 29 toddlers for this study. See Mundy *et al.* (2000) for additional sample details.

Procedures

The toddlers in this study participated in assessment sessions conducted in a developmental and psychophysiological university laboratory within 10 days of each of their 14th, 18th and 24th month birthdays.

Electrophysiological recording

Brain electrical activity (EEG) was recorded during the 14- and 18-month visits using a lycra cap. Data from the same eight head sites that were used in Mundy *et al.* (2000) were also used in this study: frontal, central, parietal and occipital regions for both the left and right hemispheres (F3, F4, C3, C4, P3, P4, O1, O2) referenced to the vertex (Cz). Baseline EEG was recorded for 3 minutes while the toddler sat quietly viewing a novel display of a rotating bingo wheel with brightly colored balls. Power was computed for the 4 to 6 and the 6 to 9 Hz frequency band. Prior results indicated that only data from the 4 to 6 Hz band were related to joint attention and communication skills in this sample (Mundy *et al.*, 2000). Therefore, only data from this frequency band was considered in this paper.

Power was expressed as mean square micro-volts and the data were transformed using the natural log (ln) to normalize the distribution. EEGANAL software (James Long Company) was used to perform spectral coherence calculations across EEG sites by averaging the normalized complex cross-spectral density within bands and epochs according to the method of Saltzberg, Burton, Burch, Fletcher and Michaels (1986). Numerous coherence pairings were possible. However, this study focused on coherence measures that had previously been observed to be associated with joint attention development (Mundy *et al.*, 2000). These included the computation of a short distance coherence variable between medial-frontal and central sites and a long distance coherence variable between medial-frontal and occipital sites. These two coherence variables were computed separately for left and right hemisphere sites using both 14- and 18-month data. At each age a summary coherence score for each hemisphere was calculated reflecting the ratio of short distance coherence divided by long distance coherence {Frontal-Central Coherence/Frontal-Occipital Coherence}. For additional details on the EEG methods employed in this study see Mundy *et al.* (2000).

Joint attention measures

Data on nonverbal joint attention behaviors were collected with the revised Early Social Communication Scales (ESCS, Mundy, Hogan & Doehring, 1996; Seibert, Hogan & Mundy, 1982). The ESCS is a 20-minute videotaped structured assessment designed to measure the development of a variety of nonverbal communication skills in the 6 to 30 month period. For this assessment an experimenter and an infant were seated facing each other across a small table. Observations of the tester–child interaction were used to yield scores for two types of joint attention behavior. Initiating Joint Attention (IJA) scores refer to the frequency with which the child spontaneously alternated eye-contact between active mechanical toys and the tester, or pointed to mechanical toys, or showed the toys. Responding to Joint Attention (RJA) refers to the percentage of 6 trials on which a child correctly turns his or her visual regard to follow the head turn and pointing gesture of the tester. A more complete description of the behaviors observed within each category is available in Mundy *et al.* (2000). Inter-rater reliability estimates based on 12 independent paired observations for data in this study yielded rs = 0.87; 0.95 ($p < 0.001$) for the frequency IJA score and percentage RJA score respectively.

Language measures

Child vocabulary development was assessed at 24 months using the Toddler form of the MacArthur Communicative Developmental Inventory (CDI, see Fenson, Dale, Resnick, Bates, Thal, Hartung & Reilly, 1994). The primary dependent measure derived from the Toddler-CDI was the number of words parents reported each child expressed. It was not clear, though, whether infant joint attention measures should be expected to relate in a linear fashion to the full range of individual differences in early vocabulary, or whether it should be expected to relate to a more basic ordinal differentiation of vocabulary skill among toddlers (Carpenter *et al.*, 1998). Therefore, outcome was also expressed as a dichotomous, median split of the MCDI vocabulary outcome data yielding a higher vs. lower 'vocabulary group' variable.

Results

The means and standard deviations for the pertinent variables in this study are presented in Table 1. The estimates of central tendency on the Toddler-CDI vocabulary measures (mean = 291 words; median = 274 words) were similar to those reported for a large sample of 24-month-olds by Fenson *et al.* (1994).

Table 1 *Means and standard deviations of the 14-, 18- and 24-month variables*

Variables	14-Month	18-Month	24-Month
ESCS			
IJA	17.0 (8.1)	17.8 (8.8)	
RJA	82% (21%)	83% (25%)	
EEG			
Left Coherence Ratio	0.61 (0.22)	0.67 (0.58)	
F3 to C3	0.20 (0.07)	0.22 (0.13)	
F3 to O1	0.35 (0.06)	0.35 (0.07)	
Right Coherence Ratio	0.64 (0.30)	0.52 (0.27)	
F4 to C4	0.21 (0.12)	0.19 (0.09)	
F4 to O2	0.35 (0.08)	0.38 (0.08)	
LANGUAGE			
MCDI Total Words			290.89 (163.07)

EEG, joint attention and language

The correlations between the parent report measures of vocabulary acquisition and the joint attention or EEG measures at 14 and 18 months can be seen in Table 2. The 14-month RJA variable, but not the 18-month measure, was significantly correlated with both the total vocabulary measure and the vocabulary group measure at a one-tailed level of analysis. One-tailed levels of analysis were appropriate because of prior observations of positive associations between infant RJA and vocabulary development (e.g. Mundy & Gomes, 1998; Mundy, Kasari, Sigman & Ruskin, 1995). Both the 14- and 18-month IJA measures displayed significant two-tailed associations with the vocabulary group measure, but not with the total vocabulary score (see Table 2). These data

Table 2 *Correlations of the EEG coherence and joint attention with language outcome*

	MCDI Total words	Vocabulary group
14-month Left-Coherence Ratio	–0.31	–0.51**
F3 to C3	–0.26	–0.35
F3 to O1	0.11	0.26
14-month Right-Coherence Ratio	–0.13	–0.15
F4 to C4	–0.10	–0.06
F4 to O2	0.12	0.27
18-month Left-Coherence Ratio	0.13	0.25
F3 to C3	0.22	0.19
F3 to O1	–0.17	–0.03
18-month Right-Coherence Ratio	0.52**	0.35
F4 to C4	0.51**	0.32
F4 to O2	0.00	–0.03
14-month IJA	0.29	0.42*
14-month RJA	0.34^	0.34^
18-month IJA	0.20	0.43*
18-month RJA	0.25	0.27

^ $p < 0.05$ (one-tailed), * $p < 0.05$ (two-tailed), ** $p < 0.01$ (two-tailed) indicated that individual differences in joint attention, as measured on the ESCS in the second year, were associated with parent reports of individual differences in subsequent lexical development.

The correlations of the EEG data with language revealed that the 14-month ratio measure of left hemisphere coherence was also correlated with the vocabulary group measure, but not the total vocabulary measure at 24 months (see Table 2). Analyses of components suggested that the association with vocabulary group was due to a negative correlation between left-frontal to left-central synchrony ($r = -0.35$, $p < 0.07$), but a positive association between left-frontal to left-occipital synchrony ($r = 0.26$) may have also contributed to the ratio coherence measure association with the vocabulary group measure. Thus, 24-month vocabulary was associated with evidence of a differentiation of left-frontal and left-central activity and some evidence of an integration of left-frontal and left-occipital activity.

Interestingly, 18-month coherence was also correlated with language development, but in this case it was a positive correlation of the right hemisphere ratio coherence measure with the total vocabulary measure (see Table 2). In addition, the association with vocabulary group approached significance ($p < 0.08$). An examination of the components suggested that this effect was largely due to a positive association of proximal synchrony between right-frontal with right-central activity at 18 months and total vocabulary at 24 months (see Table 2).

Hierarchical regression and logistic analyses were next employed to better understand the degree to which specific variables displayed direct or mediated paths of association with language development. The first regression analysis was conducted with the vocabulary group as the dependent measure. In this analysis the components of the left hemisphere EEG coherence measure at 14 months were entered on the first two steps, followed by the IJA 14-month variable. All steps of this equation were significant (see Table 3). Data from the final step indicated that lower levels of proximal left-frontal to central coherence variable, but higher levels of distal left-frontal to occipital EEG coherence variable, displayed significant paths of association with language outcome in this study. The IJA-14 variable also made a marginally significant ($p < 0.09$) positive contribution to this equation after first considering the two EEG variables. Nearly identical results for IJA were obtained when the 14-month left hemisphere ratio EEG coherence measure was used in this equation instead of the two EEG coherence component measures.

To better understand the effect sizes associated with the foregoing analysis the results of a parallel, binary logistic regression analysis have also been presented in Table 3. This analysis revealed that the combination of the 14-month left-frontal to central and left-frontal to occipital EEG coherence measures, as well as the 14-month IJA variable, combined to predict 82.1% of the vocabulary group membership at 24 months.

Table 3 *Regression analyses of 14-month joint attention and 14-month left hemisphere coherence as predictors of 24-month vocabulary group*

Steps and variables	Multiple regression			Logistic regression	
	R	Adj-R^2	β	Chi-Square	% Correct
Step 1	0.35**	0.09		3.68*	Low Group = 60.0
F3-C3			–0.35*		High Group = 53.8
Step 2	0.53**	0.22		5.14*	Low Group = 73.3
F3-C3			–0.48*		High Group = 69.2
F3-O1			0.41*		
Step 3	0.60*	0.28		3.21*	Low Group = 80.0
F3-C3			–0.39*		High Group = 84.6
F3-O1			0.36*		
IJA			0.31^		

^ $p < 0.10$, * $p < 0.05$, ** $p < 0.01$

Responding to joint attention at 14 months was not correlated with any of the 14- or 18-month ratio coherence measures in this study, but as noted earlier was correlated with language development (see Table 2). Therefore, in this study, RJA appeared to be correlated with language via a path that was not significantly associated with the ratio EEG coherence indexes of brain activity examined in this study.

Finally, multiple regression analyses were conducted to examine the degree to which 14- and 18-month EEG coherence measures combined or overlapped in their estimation of language development in this sample. Both EEG measures made robust significant contributions (range of βs = –0.39 to 0.61, ps < 0.025) to language acquisition whether measured in terms of the language group variable ($R = 0.67$; adj. $R^2 = 0.41$, $p < 0.001$) or the total vocabulary measure ($R = 0.64$, adj. $R^2 = 0.36$, $p < 0.001$). Indeed, the latter results indicated that, although left ratio EEG coherence at 14 months did not display a significant zero order association with the total vocabulary measure (see Table 2), this association was significant (β = –0.39, $p < 0.025$) after considering variance in vocabulary associated with 18-month right-hemisphere coherence.

Discussion

Consistent with findings from several recent studies (e.g. Ross & Segalowitz, 2000; Weiss & Rappelsberger, 1998), measures of EEG coherence were significantly correlated with individual differences in language abilities in this study. To the best of our knowledge, however, the observations in this study were the first to longitudinally link EEG coherence in toddlers with subsequent language development. Perhaps even more noteworthy was the observation that the pattern of relations observed between EEG coherence and language development in this study was consistent with Thatcher's (1994) theory regarding alternative maturational patterns for the left and right hemispheres.

Regression analyses indicated that the 14-month pattern of less proximal EEG coherence (left-frontal to left-central), but more distal EEG coherence (left-frontal to left-occipital), that Thatcher (1994) has suggested is a marker of left hemisphere maturation, was associated with 24-month lexical outcome. This observed connection between coherence and vocabulary may also be consistent with data indicating that working memory and memory for words specifically, may be associated with relatively more left hemisphere synchrony between distal than proximal sites (Ross & Segalowitz, 2000).

Alternatively, evidence of increased proximal synchrony in the right hemisphere at 18 months (frontal to central), that Thatcher (1994) has suggested is a marker of right hemisphere maturation, was also associated with language development. In turn, this observation was consonant with other research indicative of right hemisphere involvement in early language acquisition (Bates, Thal, Trauner, Fenson, Aram, Eisele & Nass, 1997; Neville & Mills, 1997).

These results provide support for the potential utility of EEG coherence measures in the study of brain–behavior relations in early development, and especially Thatcher's (1994) initial theory regarding these measures. Moreover, the data from regression analyses suggested that measures of left and right hemisphere coherence, acquired between 14 and 18 months, may provide unique information about variability in early language development. Unfortunately, though, too little is currently known about the nature and measurement of EEG coherence (Nunez, Silberstein, Shi, Carpenter, Srinivasan, Tucker, Doran, Cadusch & Wijesinghe, 1999) to precisely interpret the nature of the coherence to language associations observed in this study. Moreover, this study only examined a very limited set of coherence measures. Studies that employed EEG data from temporal sites or other frontal sites may yield additional or different information on EEG coherence and early social-communication development.

Nevertheless, the present results were sufficiently substantive to be heuristic and to encourage further research into the nature, meaning and measurement of EEG coherence in the study of infant development. Moreover, they raise several interesting questions. For example, if the differentiation of left-central and left-medial-frontal processes in the second year is a specific correlate of both joint attention and language development, what psychological functions are related to this neurodevelopmental process? Perhaps the beginning of an answer to this question may emerge from data that suggest that left-medial-frontal cortical activity may be specifically involved in social cognition (Frith & Frith, 1999, 2001; Mundy *et al.*, 2000). Alternatively, medial-frontal processes may involve more general, less specifically social cognitive facilities that are also relevant to joint attention and language development (e.g. Ferstl & von Cramon, 2001; Luu, Flaisch & Tucker, 2000).

This study also begins to provide some clarity with respect to processes involved in the link between joint attention and later language development. As expected initiating joint attention skill at 14 months was also a significant predictor of parent report language measures at 24 months. Moreover, initiating joint attention at 14 months has also been associated with the differentiation of left-frontal and left-central EEG activity in this sample (Mundy *et al.*, 2000). Thus, some element of the commonly observed linkage between initiating joint attention and language may involve basic infant brain-related maturation processes. This suggests that the corpus of theory or research on the links between joint attention and language are likely to be incomplete, if not incorrect, unless they also consider brain–behavior processes. Nevertheless, even after considering the covariance between EEG and initiating joint attention measures, the latter still displayed evidence of marginally significant relations with early lexical development. Moreover, the responding to joint attention measures were also related to language development, but were not related to EEG measures in this study. Thus, it was difficult to completely account for the relations between joint attention and language development in terms of the EEG indices of neural processes used in this study.

Obviously, one possibility here is that more complete or sophisticated assessments of brain-behavior relations would reveal that the preponderance of the variance shared between joint attention measures and early language development may be solely ascribed to covariance with neuro-developmental processes. Another possibility, though, is that biological processes may contribute to the development of the ability for joint attention and language, but the child's utilization of joint attention skills also contributes to their own cognitive and linguistic development (Baldwin, 1995). Furthermore, variability in the tendency to utilize joint attention ability may be affected by caregiver behavior (Flannagan, Coppa, Riggs & Alaro, 1994; Claussen, Mundy, Mallik & Willoughby, in press) and more general aspects of the home social environment (Wachs & Chan, 1986). Thus, individual differences in the development and display of joint skills may reflect both basic brain maturation processes and environmental processes. Moreover, each of these domains, along with self-organizing properties (Baldwin, 1995; Mundy & Neal, 2001), may contribute to the fundamental link between infant joint attention and subsequent social and cognitive development.

Acknowledgements

Preparation of this paper was supported, in part, by NICHD grants 26768 (Fox) and 00484 (Mundy).

References

Bakeman, R., & Adamson, L. (1984). Coordinating attention to people and objects in mother infant and peer infant interactions. *Child Development*, **55**, 1278–1289.

Baldwin, D. (1995). Understanding the links between joint attention and language. In C. Moore & P.J. Dunham (Eds.), *Joint attention: Its origins and its role in development* (pp. 131–158). Hilldale, NJ: Erlbaum.

Bates, E. (1999). Language and the brain. *Journal of Communication Disorders*, **32**, 195–205.

Bates, E., Thal, D., Trauner, D., Fenson, J., Aram, D., Eisele, J., & Nass, R. (1997). From first words to grammar in children with focal brain injury. *Developmental Neuropsychology*, **13**, 275–343.

Bell, M., & Fox, N. (1996). Crawling experience is related to changes in cortical organization during infancy: evidence from EEG coherence. *Developmental Psychobiology*, **29**, 551–561.

Caplan, R., Chugani, H., Messa, C., Guthrie, D., Sigman, M., Traversay, J., & Mundy, P. (1993). Hemispherectomy for early onset intractable seizures: pre-surgical cerebral glucose metabolism and post surgical nonverbal communication patterns. *Developmental Medicine and Child Neurology*, **35**, 574–581.

Carpenter, M., Nagell, K., & Tomasello, M. (1998). Social cognition, joint attention and communicative competence from 9 to 15 months of age. *Monographs of the Society of Research in Child Development*, **63**, no. 4.

Claussen, A., Mundy, P., Mallik, S., & Willoughby, J. (in press). Joint attention and disorganized attachment in infants at risk. *Development and Psychopathology*.

Fenson, L., Dale, P., Resnick, S., Bates, E., Thal, D., Hartung, J., & Reilly, J. (1994). Variability in early communication development. *Monographs of the Society for Research in Child Development*, **59** (5, Serial No. 242).

Ferstl, E., & von Cramon, D. (2001). The role of coherence and cohesion in text comprehension: an event related fMRI study. *Cognitive Brain Research*, **11**, 325–340.

Fischer, K., & Rose, S. (1994). Dynamic development of coordination of components in brain and behavior: a framework for theory and research. In G. Dawson and K. Fischer (Eds.), *Human behavior and the developing brain* (pp. 3–66). New York: Guilford Press.

Flannagan, P., Coppa, D., Riggs, S., & Alaro, A. (1994). Communication behaviors of infants of teen mothers. *Journal of Adolescent Health*, **15**, 169–175.

Frith, C., & Frith, U. (1999). Interacting minds: a biological basis. *Science*, **286**, 1692–1695.

Frith, U., & Frith, C. (2001). The biological basis of social interaction. *Current Directions in Psychological Science*, **10**, 151–155.

Kawashima, R., Sugiura, M., Kato, T., Nakamura, A., Natano, K., Ito, K., Fukuda, H., Kojima, S., & Nakamura, K. (1999). The human amygdala plays an important role in gaze monitoring. *Brain*, **122**, 779–783.

Luu, P., Flaisch, T., & Tucker, D. (2000). Medial frontal cortex in action monitoring. *Journal of Neuroscience*, **20**, 464–469.

Mundy, P., Card, J., & Fox, N. (2000). EEG correlates of the development of infant joint attention skills. *Developmental Psychobiology*, **36**, 325–338.

Mundy, P., & Gomes, A. (1998). Individual differences in joint attention skill development in the second year. *Infant Behavior and Development*, **21**, 469–482.

Mundy, P., Hogan, A., & Doehring, P. (1996). *A preliminary manual for the abridged Early Social-Communication Scales*. Coral Gables, FL: University of Miami, www.psy.miami.edu/faculty/pmundy.

Mundy, P., Kasari, C., Sigman, M., & Ruskin, E. (1995). Nonverbal communication and early language in Down syndrome and in normally developing children. *Journal of Speech and Hearing Research*, **38**, 157–167.

Mundy, P., & Neal, R. (2001). Neural plasticity, joint attention and autistic developmental pathology. In L. Glidden (Ed.), *International Review of Mental Retardation Research*, **27**, 139–168.

Neville, H., & Mills, D. (1997). Epigenesis of language. *Mental Retardation and Developmental Disabilities Reviews*, **3**, 282–292.

Nunez, P., Silberstein, R., Shi, Z., Carpenter, M., Srinivasan, R., Tucker, D., Doran, S., Cadusch, P., & Wijesinghe, R. (1999). EEG coherency II: experimental comparisons of multiple measures. *Clinical Neurophysiology*, **110**, 469–486.

Ross, P., & Segalowitz, S. (2000). An EEG coherence test of the frontal dorsal versus ventral hypothesis in n-back working memory. *Brain and Cognition*, **43**, 375–379.

Saltzberg, B., Burton, D.B., Burch, N.R., Fletcher, J., & Michaels, R. (1986). Electro-physiological measures of regional neural interactive coupling. Linear and non-linear dependence relationships among multiple channel electroencephalographic recordings. *International Journal of Bio_Medical Computing*, **18**, 77–87.

Seibert, J.M., Hogan, A.E., & Mundy, P.C. (1982). Assessing interactional competencies: the Early Social-Communication Scales. *Infant Mental Health Journal*, **3**, 244–245.

Thatcher, R. (1994). Cyclical cortical reorganization: origins of human cognitive development. In G. Dawson and K. Fischer (Eds.), *Human behavior and the developing brain* (pp. 232–268). New York: Guilford Press.

Tomasello, M. (1988). The role of joint attention in early language development. *Language Sciences*, **11**, 69–88.

Ulvund, S., & Smith, L. (1996). The predictive validity of nonverbal communication skills in infants with perinatal hazards. *Infant Behavior and Development*, **19**, 441–449.
Wachs, T., & Chan, A. (1986). Specificity of environmental action, as seen in environmental correlates of infants' communication performance. *Child Development*, **57**, 1464–1474.
Weiss, S., & Rappelsberger, P. (1998). Left frontal EEG coherence reflects modality independent language processes. *Brain Topography*, **11**, 33–42.

Received: 27 March 2001
Accepted: 14 November 2001