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What Does Fetal Movement Predict About Behavior During the First Two Years of Life?

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ABSTRACT: *This study evaluated whether motor activity prior to birth is predictive of motor behavior and temperament in neonates, infants, and toddlers. Three measures of fetal motor activity (activity level, amplitude, and number of movements) were collected at 24, 30, and 36 weeks of gestation in 52 healthy fetuses using Doppler-based actography. Postnatal data collection included a neurobehavioral assessment at 2-weeks postpartum ($n = 41$), and laboratory-based behavioral observations at 1 and 2 years of age ($ns = 35$). Individual stability in motor activity was present during gestation. Predictive relations between fetal movement and neonatal behavior were inconsistent; significant but small positive associations were detected between motor behavior at 36 weeks and neonatal irritability and motor development. Fetal activity level at 36 weeks was positively associated with observed 1-year activity level for boys (but inversely related for girls) and maternal report of activity level at 2 years. Fetal movement was consistently and negatively predictive of distress to limitations at 1 year and behavioral inhibition at 2 years, accounting for 21 to 43% of the variance in these measures. Intrafetal variability in motor behavior makes this a*

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relatively unstable metric for prediction to neonatal maturational outcomes, which are relatively constrained, but fetal motor activity appears to predict temperament attributes related to regulatory behaviors in early childhood. Dev Psychobiol 40: 358–371, 2002. Published online in Wiley InterScience (www.interscience.wiley.com). DOI 10.1002/dev.10025

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> "Perhaps the most important objective . . . is to secure sufficiently reliable criteria of fetal activity and reactivity so that these variables measured in the fetal period may be related to others measured in post-natal life" (Sontag & Richards, 1938, p. 64).

Prominent among the goals of the Fels study of fetal behavior of the 1930s was understanding the prenatal antecedents of subsequent development. Then, as now, fetal motor behavior is considered to be a core feature of fetal functioning. Although developmentalists have had longstanding interest in this question, recent models of fetal programming of autonomic function in later life (Barker, 1995; Nathanielsz, 1999) have contributed to a resurgence in interest in the fetal period in the biomedical and psychobiological communities.

Motor activity is one of the most commonly investigated aspects of fetal behavior. Spontaneously generated motor activity is present early in the embryo; movements become more complex and differentiated as the fetus progresses through gestation (deVries, Visser, & Prechtl, 1982; Ianniruberto & Tajani, 1981; Roodenburg, Wladimiroff, van Es, & Prechtl, 1991). In general, in the latter half of gestation, fetuses move approximately once per minute, and are active between 10 and 30% of the time (DiPietro, Costigan, Shupe, Pressman, & Johnson, 1998; Groome et al., 1999; Nasello-Paterson, Natale, & Connors, 1988; Roberts, Griffin, Mooney, Cooper, & Campbell, 1980).

Motor activity is also a core construct pertaining to individual differences after birth and has been the most widely studied and validated dimension of early temperament (Fagot & O'Brien, 1994; Goldsmith et al., 1987; Hubert, Wachs, Peters-Martin, & Gandour, 1982; Rothbart & Ahad, 1994). Activity level is typically defined in terms of energy expenditure and arousal, although operationalization of this construct varies based on developmental stage and locomotor proficiency (Eaton & Enns, 1986). Constitutionality is a central component to temperament theory; support for the constitutional nature of activity level includes evidence of individuality (Eaton & Saudino, 1992), genetic contribution (Saudino & Eaton, 1995), and stability from early to later ages within and across infancy and early childhood (Fagot & O'Brien, 1994; Korner et al., 1985; McBride-Chang, Gallahan, & Jacklin, 1996; Rothbart, 1986; Schaughency & Fagot, 1993). Although neurobehaviorists have long contended that parturition does not represent a significant demarcation in neural development (Als, 1982; Prechtl, 1984), relatively few studies have attempted to examine stability or consistency within individuals from before to after birth due to the limited accessibility of the fetus. The handful of studies that have attempted this have generated inconsistent results. In one of the first, fetal motor activity as measured by maternal report was not found to be associated with observed activity in the neonate ($n = 29$) or in 1-year-olds ($n = 22$) (Shadmi, Homburg, & Insler, 1986). However, Groome (Groome et al., 1999) reported findings of stability in motor activity in 22 term fetuses measured during the first month of life using comparable techniques: Fetal body movements, inferred from ultrasound visualization of the fetal head, were significantly associated with infant movements ($r = .73$ between last fetal and first infant recordings) during active sleep. In one of the most thorough longitudinal studies regarding movement, stability in the number of leg movements at 37 weeks, observed using ultrasound, was significantly correlated with postnatal leg movements during sleep for neonatal girls ($r = .73$), but not for boys (Almli, Ball, & Wheeler, 2001). Fetal to infant stability was not evidenced at 6 weeks in this sample of 37 infants. Although others have reported consistencies in fetal and infant motor characteristics (Pillai & James, 1990; Robertson, 1987), those reports did not present data analyses at the level of the individual. Although it is generally assumed that the role of fetal movement, in part, is to prepare the musculature for postnatal motor function, no studies address whether individual differences in fetal motor activity predict later motor development. One investigation has reported heterotypic consistencies between fetal motor activity and another aspect of infant temperament. Maternally detected fetal movements ($n = 20$) near term were significantly predictive of the frequency of infant crying through the first 3 months of life

($r = .56$) (St. James-Roberts & Menon-Johansson, 1999).

In an earlier sample of 31 fetuses, we reported significant, positive relations between fetal activity level at 36 weeks as quantified by an actograph and maternal reports at 3 and 6 months of age of infant activity level (rs = .40 and .37, respectively) and difficult temperament (rs = .52 & .60) (DiPietro, Hodgson, Costigan, & Johnson, 1996b). However, there remains the possibility that experiences with the fetus before birth contribute to later maternal perceptions and report of temperament independently of infant behavior (Zeanah, Keener, & Anders, 1986). That is, maternal expectations about how the infant will behave based on perceived fetal activity may persist through early infancy and be reflected in maternal reports. The current study was designed to examine the predictive, within-domain relations between fetal motor activity and postnatal motor development and activity level as well as cross-domain measures of infant temperament using direct observation of child behavior at 6 weeks, 1 year, and 2 years.

Hypothesis generation was based on existing literature on motor activity during the postnatal period. Contemporaneous activity level has been negatively associated with motor maturity during Years 5 to 8 (Eaton & Yu, 1989) and higher activity level at age 2 predicts less mature motor development at age 7 (Halverson & Waldrop, 1976), suggesting that high levels of spontaneous activity are indicators of immaturity. Cross-domain associations with other aspects of temperament also have been found; higher neonatal activity level is positively associated with higher approach to novelty (Korner et al., 1985) and emotionality (Riese, 1987) in early childhood. Motor activity is one component, in conjunction with affect, of a typology that predicts later behavioral inhibition (Calkins, Fox, & Marshall, 1996). Boys tend to be more active than girls, although detection of sex effects vary by age and context (Campbell & Eaton, 1999; Eaton & Enns, 1986). A fetal sex difference in aspects of motor behavior favoring males has been reported in some studies (Almli et al., 2001; DiPietro, Hodgson, Costigan, Hilton, & Johnson, 1996a) but not others (DiPietro et al., 1998; Groome et al., 1999; Pillai & James, 1990). Based on the existing literature, we expected that greater movement in the second half of gestation will predict reduced motor development in the neonatal and infant periods, higher activity level, and characteristics of temperament associated with regulatory control and that fetal sex may moderate these relations.

METHODS

Participants

Participants were 52 nonsmoking women with singleton pregnancies and their offspring. Inclusion criteria included low risk, uncomplicated pregnancies with stringent gestational age dating criteria. Demographic and medical data were collected by interview and medical chart review. Prepregnancy, pregnancy, and intrapartum risk factors were summarized using existing scales (Hobel, Hyvarinen, Okada, & Oh, 1973). All infants included in this analysis were delivered at term (i.e., 37- to 41-weeks of gestation) and discharged from the regular newborn nursery according to routine schedules. Although there was a range in their demographic characteristics, the sample consisted of primarily healthy, well-educated, and employed women. Seventy-seven percent of participants were European American; the remainder were African American (9.6%) and Asian/Asian American (13.4%). Forty-one neonates (79%) returned for testing at 2 weeks postnatal age; 35 (67%) returned for the 1- and 2-year assessments, although these were not all the same infants (i.e., 29 children participated at both 1 and 2 years). However, there were no differences in fetal movement, neonatal, or demographic characteristics between tested and untested children at any of the three ages. Maternal and fetal characteristics of participants at each postnatal age are included in Table 1.

DESIGN AND PROCEDURES

Fetus

Data were collected at 24, 30, and 36 weeks' gestational age. To control for potential diurnal and prandial effects, fetal behavior was assessed at the same time at each age, either at 1:00 or 3:00 p.m. Women were instructed to eat 1½ hr prior to testing, but not again before testing. Women were monitored for 50 min in a left lateral recumbent position while resting quietly. Data were available for all 52 fetuses at each gestational age.

Fetal movement (FM) data were collected from a fetal actocardiotocograph (Toitu, MT320, Tokyo, Japan). This monitor generates both fetal heart rate and body movement using a single wide array Doppler transducer positioned on the maternal abdomen. The focus of this analysis is on the fetal body movement output alone; associations between fetal and infant heart rate data are described in another

Table 1. Maternal and Infant Characteristics

	Antenatal		Neonatal		1 Year		2 Year	
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
N	52		41		35		35	
Maternal age	29.9	3.5	29.9	3.3	30.2	3.3	30.2	3.1
Maternal education (Years)	16.3	2.6	16.4	2.6	16.3	2.6	16.1	2.5
Prepregnancy risk score	3.0	5.3	3.4	5.8	2.6	3.3	3.0	5.8
Pregnancy risk score	1.7	2.7	1.7	2.8	2.0	3.0	1.9	3.0
Intrapartum risk score	8.2	8.5	7.8	8.1	8.5	8.7	7.0	8.6
Gestational age at delivery	39.6	1.1	39.6	1.1	39.7	1.2	39.7	1.0
Infant birth weight	3502	470	3525	454	3534	461	3550	439
5-min Apgar	8.9	.5	8.9	.6	8.9	.6	9.0	.5
%boys	60		56		60		57	
%primiparous	64		66		69		63	

report (DiPietro, Costigan, Pressman, & Doussard-Roosevelt, 2000). Data were digitized at 5 Hz using an A–D converter board and commercial data collection package that had been adapted for our purposes (LabVIEW NB, National Instruments Corp., Austin, TX). The fetal actograph component of the monitor bandpasses both the highest frequency (i.e., fetal heart motions) and the lowest frequency signals (i.e., maternal movement and respiration) detected in the uterus. Actograph signals are generated by a change in the returned Doppler waveform; if there is no movement, the returned signal will retain the same frequency as the emitted signal. If the fetus is moving, the echo will be returned at a different frequency, which is commensurate with the velocity with which the fetal body part moves towards or away from the transducer. The actograph signal is output in arbitrary units (a.u.s.) ranging from 0 to 100. The validity of this brand of monitor to accurately detect fetal motor activity has been well documented, with identification of 91 to 95% of all ultrasound-visualized movements whether agreement is based on time intervals or individual movements, and is equally reliable in detecting periods of quiescence (Besinger & Johnson, 1989; DiPietro, Costigan, & Pressman, 1999; Maeda, Tatsumura, & Nakajima, 1991; Maeda, Tatsumura, & Utsu, 1999; Ohta, 1985). Most movements undetected by the actograph are small, isolated movements of extremities; virtually all (97–98%) trunk and sustained (>1 s) movements are detected; conversely, the actograph can detect those movements that occur beyond the ultrasound field.

Three movement measures were computed from the digitized actograph data.

Movement Bouts. A movement bout was defined as commencing each time the actograph signal attained or exceeded 25 a.u.s. and terminating when the signal fell below 25 a.u.s. for at least 10 consecutive seconds Signals of less than 25 a.u.s. may result from calibration variability or small fetal motions including breathing and hiccups (Maeda et al., 1991); this threshold provides conservative movement detection.

Movement Amplitude. A mean of the level of actograph activity in each 1-min epoch, averaged over the 50 min was computed. This value represents the overall magnitude of the actograph signal as an indicator of movement vigor.

Activity Level. The number of movement bouts was multiplied by the mean bout duration to provide a measure of the total amount of time (min) the fetus was active during the 50-min recording.

These three movement measures were interrelated (averaged *r*s across gestation = .53 for bouts and activity level, .53 between bouts and amplitude, and .92 for activity level and amplitude). Despite this colinearity, we retained all three measures for analysis because each provides a relatively distinct construct of fetal movement, and each has traditionally been used in different domains of investigation including obstetrics, psychobiology, and child development.

Neonate

Infant data collection was conducted in the morning between anticipated feedings. Mean age at testing was 14.2 days postpartum (*SD* = 1.9, range = 9–18 days). A standard neurobehavioral assessment, the Neonatal Assessment of the Preterm Infant (NAPI; Psychological Corp.), was administered. The NAPI evaluates features of neonatal motor development, state regulation, and responsivity to stimuli. Although this scale was developed for use with preterm infants, it was selected because of the rigorous psychometric testing undertaken for scale development (Korner et al., 1987; Korner, Constantinou, Dimiceli, Brown, & Thom, 1991), reports of the use of this scale with full-term infants by other investigators (Brown, Bakeman, Coles, Sexon, & Demi, 1998), and relevance of several derived factors to our research questions.

The exam proceeds in an invariant sequence of manipulations and observations. Raw scores are converted to standardized scores before compositing into factors. Four of the five scores derived from this exam are germane to this analysis. The popliteal angle and the scarf sign are both measures of neuromuscular maturity. The former yielded little variability in these full-term infants and was not used in the analysis. The scarf sign is assessed by moving the arm across the chest, and the point at which resistance is encountered is recorded. The scale is scored on a 4-point scale, with higher scores indicating greater neuromuscular maturity. Motor maturity was evaluated by the Motor Development and Vigor cluster, which includes the following items: forearm recoil, ventral suspension, prone head raising, spontaneous crawling, power of active movements of arms and legs, and vigor of spontaneous movements. The Irritability cluster is based on the extent to which the infant cried during the assessment. A single examiner (J.D.) who was certified in administration of this scale and unaware of fetal values at the time of testing conducted each assessment.

One-Year-Infant Assessment

At 1 year (*M* age = 53.4 weeks; *SD* = 1.0), infant behavior was assessed using four episodes of the Laboratory Temperament Assessment Battery (Lab-TAB) (Goldsmith & Rothbart, 1988). Two vignettes were used to elicit gross motor behavior: (a) Free-Play situation, in which the child is provided with 10 different toys, displayed in an array on the floor, and allowed free locomotion and unstructured play for 6 min; and (b) Corral Enclosure, during which the child is placed in a 2.5-m diameter, circular enclosure filled with differently sized balls for 3 min. Two other vignettes were used to elicit frustration and assess behavior during restraint: (a) Attractive toy placed behind barrier, involving three trials of sequestering a toy behind a Plexiglas barrier (30 s each) while the child is seated out of reach; and (b) Restraint in car seat, during which the child is placed and buckled into a car seat for 30 s. Episodes were videotaped for coding.

Administration and scoring of these episodes is highly structured. Three undergraduates were trained to code the videotaped data following standard Lab-TAB scoring definitions. Coders were blind to fetal and neonatal results. Eleven videotapes (31%) were randomly selected for reliability training. Kappa (κ) statistics were computed for nominal variables based on ratings; intraclass correlation coefficients (ICC) were used for continuous measures. Behaviors included in final composites were not subtle, and intercoder agreement was high. Reliability information is included within each composite description.

There are no a priori factors for reducing Lab-TAB variables prior to data analysis. Guidelines provided in the Lab-TAB manual, based on preliminary examination of relations within and across episodes, were followed. Based on sample size, we endeavored to restrict compositing to two final motor variables (activity level and motor development) and one for distress to limitations.

Activity Level. Ratings of energy and vigor during the two gross motor activity episodes (Corral and Free Play) rated on 5-point scales (0–4) were significantly correlated ($r = .50$). These variables were averaged to provide a single measure of activity level (ICC = .93).

Motor Development. A range of locomotor proficiency was present at 12 months. Children were scored on their highest level of motor proficiency displayed during the Free Play and Corral episodes as follows: crawls, stands, walks, runs, and climbs ($\kappa = 1.00$).

Distress to Limitations. Elicited behaviors with acceptable distributions included operating on the Plexiglas barrier with varying degrees of force and struggling to get out of the car seat. Interrater reliabilities were as follows: (a) intensity of force displayed against barrier and degree of upset, (b) struggle against the car seat (κs = .89 and .85, respectively), and (c, d) number of reaches towards toy and contacts with barrier (ICC = .99 for both). Variables were *Z*-scored and summed for compositing.

Two-Year Toddler Assessment

The final assessment occurred during a home visit between 25 and 30 months (*M* age = 27.0 months, *SD* = .9). Children were videotaped while playing alone on the floor for 10 min. Mothers sat nearby with some paperwork, but were asked to refrain from interacting. A set of standard, age-appropriate toys was provided, and play was unstructured. Training and interrater reliability procedures were conducted as for the 1-year visit. Coders were blind to fetal, neonatal, and 1-year results. After training to criterion, 25% of the videotapes were randomly selected for reliability evaluation.

Inhibition. The following child behaviors (followed by intercoder reliability information) were coded to assess behavioral inhibition: (a) amount of time spent playing with the toys (ICC = .99), (b) frequency of positive vocalizations not directed to mother or experimenter (ICC = .98), (c) frequency of vocalizations directed to the experimenter (ICC = .94), (d) amount of time spent in close proximity to experimenter ($\kappa = .73$), (e) amount of time spent in close proximity to mother ($\kappa = .85$), (f) amount of time child spent in physical contact with mother ($\kappa = .76$), and (g) number of times the child looked toward mother (ICC = .95). Components a, b, c, and d were reverse scored. Behavioral inhibition inhibition was calculated as the sum of each trichotomized score (based on median split where 1 = below median; 1.5 = median, and 2 = above median); a higher score indicates greater inhibition during the testing session.

Activity Level. Activity level was not directly measured at the 2-year visit because the situation was designed to examine inhibitory behavior and not to encourage gross motor activity. As might be expected in a situation such as this, toddler locomotion was positively related to seeking maternal contact ($r = .33$, $p = .05$). Given the relevance of activity level to the current analysis, children's normative activity level information was provided by maternal report on the activity level dimension of the Toddler Behavior Assessment Questionnaire (TBAQ) (Goldsmith, 1996), which was mailed prior to the home visit. This dimension is one of five subscales and includes items that assess limb, trunk, or locomotor movement during a variety of daily situations including free play, confinement, or quiet activities. In a standardization sample of one hundred two 18- to 24-month-olds, the internal consistency for this dimension was high ($\alpha = .78$) (Goldsmith, 1996). Maternal reports of activity level in children have been found to be significantly associated with behavioral observations (Rothbart, 1986; Schaughency & Fagot, 1993).

Analysis Plan. Fetal measures were examined for gestational age effects and groups differences based on infant sex and maternal parity (first born vs. later born) using repeated measures analysis of variance (ANOVA); evaluation of postnatal outcome differences were based on t tests. Assessment of prenatal associations relied on Pearson correlational analyses; multiple regression formed the core of the predictive analyses to postnatal measures. Separate regressions, in which the fetal movement measures were entered at all three gestational ages, were computed for each behavioral outcome. Interaction terms for sex were included when examination of bivariate correlations suggested different patterns of associations among dependent and independent measures. In other cases, sex was entered as a control variable when sex differences were detected in the preliminary analyses. To retain power, analyses were not restricted to the subsample for whom data were available at all four time points; rather, the maximal number of participants available at each time period was included. Because this is largely an exploratory study, statistical inference was based on two-tailed p values throughout, unless when evaluating stability of the same construct, as noted in the text.

RESULTS

Fetal Assessment

Means and *SD*s for the three fetal movement measures (bouts, amplitude, and activity level) are provided in Table 2. Two significant outliers (Tukey, 1977), were detected for Activity Level at 36 weeks (values = 38.1 and 40.3; next-highest value = 19.7). Examination of raw data revealed no indications of measurement artifact, and for one of these individuals the 30-week recording was also the highest recorded, although not an outlier. However, because of the

Table 2. Fetal Measures at 24, 30, and 36 Weeks' Gestation ($n = 52$)

	Movement Bouts		Movement Amplitude		Activity Level	
	M	*SD*	*M*	*SD*	*M*	*SD*
24 weeks	61.1	15.6	8.39	2.7	10.0	5.9
30 weeks	54.2	20.0	8.06	4.3	9.0	7.8
36 weeks	49.2	20.8	8.43	4.7	8.5	7.9

disproportionate influence of outliers on correlations, 36-week Activity Level data from these 2 fetuses were excluded from analyses. The descriptive values in Table 2 were reported previously as those for one of two cohorts in a larger analysis focused on developmental trends during the fetal period alone (DiPietro et al., 1998). Movement Bouts and Fetal Activity Level declined significantly over gestation, $F(2, 102) = 7.47$, $p < .001$, and $F(2, 98) = 4.19$, $p < .05$. As reported previously, no sex differences or Sex × Gestational Age interactions for any of the fetal movement measures were detected. Maternal parity was not associated with fetal movement.

Table 3 presents intercorrelations of fetal movement measures over time. All intercorrelations are positive from 24 weeks, but only the associations between 30 and 36- weeks for Amplitude and Amplitude and Bouts attained significance (ps $< .001$). Activity Level demonstrates significant associations beginning at 24 weeks.

Infant Assessments

Descriptive information for all postnatal behavioral measures, including those that are components of the *Z*-scored composites, are presented in Table 4.

Neonate. There were no significant sex differences in neonatal measures. Maternal parity was associated with the Scarf Sign, $t(39) = 3.07$, $p < .01$, with first-born infants exhibiting less maturation than later-born infants. During the NAPI assessment, infant behavioral state is scored at 14 intervals, the majority of these during aversive maneuvers, using standard scoring criteria (Brazelton, 1984), including quiet sleep (1), active sleep (2), drowsiness (3), quiet alertness (4), active waking (5), and crying (6). An average of these values ($M = 4.6$, $SD = .6$) provides an indicator of overall state level during testing. Infant state was highly associated with scores on the Motor and Vigor cluster, $r(39) = .60$, $p < .001$, but not the Scarf Sign, $r(39) = .02$. It is likely that this association results from the higher muscular tone that accompanies higher behavioral states. To control this source of error, infant state was included first in the regression analysis of this cluster.

None of the overall regressions for any neonatal measure attained significance when movement measures at all three gestational ages were entered together. Multiple *R*s ranged from .27 to .33 for Scarf Sign, from .17 to .30 for Motor Development and Vigor, and from .16 to .36 for Irritability. There were three instances of regressions in which fetal movement at a specific gestational age was significantly associated with neonatal performance. These are presented in Table 5 and include the unstandardized coefficients, *SE*s of B, *t* values for each individual week of gestation, and correlation coefficient (partial correlation for Motor cluster). Significant positive associations were detected between Movement Amplitude at 30 weeks and Scarf Sign, Movement Amplitude at 36 weeks and Motor Development and Vigor, and 36-week Movement Bouts and Irritability.

1-Year Assessment

Activity Level. The activity level composite is based on a 5-point scale of 0 (*low*) to 4 (*high*). Composite scores for 2 infants could not be constructed due to videotape failure (1) and child refusal to participate (1), both during the Corral segment. There was a significant sex difference on the activity level composite, $t(30) = 2.41$, ps $< .05$, with boys displaying greater activity. During exploratory bivariate analyses, consistent disparities were observed in the directions of correlations for boys and girls between the fetal movement measures and infant activity, so Sex × Fetal Movement interaction terms for each gestational age were included in the regressions. The interactions were significant and similar in magnitude for each of the three fetal movement measures at every gestational age (ts range from -2.12 to -3.23, $p < .05$ and $.01$), indicating that the association between fetal measures and infant activity varies by infant sex. No consistent pattern could be detected in the correlations, although when

Table 3. Intercorrelations of Fetal Measures During Gestation ($n = 52$)

	Movement Bouts			Movement Amplitude			Activity Level		
	24	30	36	24	30	36	24	30	36
24 weeks	—	.15	.23	—	.23	.14	—	.21	.39*
30 weeks		—	.51**		—	.44**		—	.51**

*$p < .01$. **$p < .001$.

Table 4. Neonatal, Infant, and Toddler Behavioral Measures

	M	*SD*
Neonate ($n = 41$)		
Scarf sign	70.3	25.4
Motor development & vigor	69.5	16.6
Irritability	49.8	22.6
One year ($n = 35$)		
Activity level composite (Z)	.1	1.8
Free play	2.1	.6
Corral	2.5	.6
Motor development	3.7	1.3
Distress to limits composite (Z)	0	2.5
Barrier force	2.4	.8
Barrier push	4.2	2.5
Barrier reach	5.3	2.9
Car seat upset	2.4	1.1
Two year ($n = 35$)		
Inhibition	10.3	1.5
Activity level	4.3	.8

correlations approached significance, they tended to be positive for boys but negative for girls. The correlations between 36-week Movement Bouts and infant Activity were $r(17) = .40$, $p < .10$ for boys, but $r(12) = -.47$, $p < .10$ for girls; those for Activity Level and infant Activity were $r(16) = .45$, $p = .06$ for boys, but $r(11) = -.40$ for girls; differences between these pairs of correlations are significant (Zs $= 2.39$ and 2.23, respectively, ps $< .05$). Figure 1 illustrates these effects: The 36-week fetal activity level was stratified at the mean into low and high levels. The 2×2 ANOVA interaction term is significant; Activity Level $\times$ Sex, $F(1, 29) = 5.80$, $p < .05$.

Table 5. Prediction of Neonatal Measures from Fetal Movement ($n = 41$)

	Fetal Movement[a]			
	B	*SE*	*t*	*r*
Scarf Sign				
24 weeks	−.80	1.41	−.57	−.02
30 weeks	2.13	1.03	2.06**	.31**
36 weeks	−.34	.87	−.40	.08
Motor development & vigor				
24 weeks	−.96	.76	−1.27	−.15[b]
30 weeks	−.59	.55	−1.06	−.09
36 weeks	.92	.45	2.05**	.22
Irritability				
24 weeks	.00	.02	−.22	.03
30 weeks	−.02	.02	−1.31	−.07
36 weeks	.04	.02	2.27**	.29*

[a]Results based on fetal movement amplitude for Scarf Sign and Motor Development; Movement Bouts for Irritability. Remaining variable associations not included in table did not attain significance at any gestational age. [b]Partial correlations, after controlling for infant behavioral state.
*$p < .10$. **$p < .05$.

Motor Maturity. The distribution of motor behavior was as follows: crawl (9), stand (3), walk (15), run (4), and climb (4). No sex difference was detected, and the multiple regressions for each fetal movement measure at three gestational ages did not attain significance. There was a single significant finding at 30 weeks: Higher fetal activity was associated with reduced motor maturity, $t = -2.13$, $\beta = -.42$, $p < .05$.

Distress to Limitations. Composite scores could not be computed for 1 child because of videotape failure. Boys displayed significantly more reaction during the Barrier and Car Seat episodes, evidenced by a sex difference in Distress to Limitations, $t(32) = 2.73$, $p < .01$. Consistent differences in patterns of correlations within sex were not apparent, so sex was used only as a control variable. Its entry into the initial step of regressions did not affect relations between the dependent and independent measures; unadjusted regression results are presented in Table 6. The significant overall F values indicated that fetal movement amplitude and activity level across gestational age were both significantly associated with Distress to Limitations, each accounting for 43% of variance; Movement Bouts were not associated. Because substantial covariation existed among the relations between movement measures at each gestational age and Distress, obscuring the predictive associations particularly with respect to the latter two ages, values for each gestational age were entered on sequential steps of the regression so that separate estimates would be constructed. Results indicated that Amplitude is consistently and negatively associated with Distress to Limitation across gestational ages; the overall model was significant for Activity Level, but the association was limited to 24 and 30 weeks.

2-Year Assessment

Inhibition. There was no sex difference in Inhibition, $t(33) = .50$, and examination of the pattern of correlations did not reveal differences by sex. Results of the fetal movement regressions, computed in the same manner as for Distress to Limitations because of similar covariation, are presented in Table 6. All three fetal movement measures were significantly predictive of behavioral inhibition, accounting

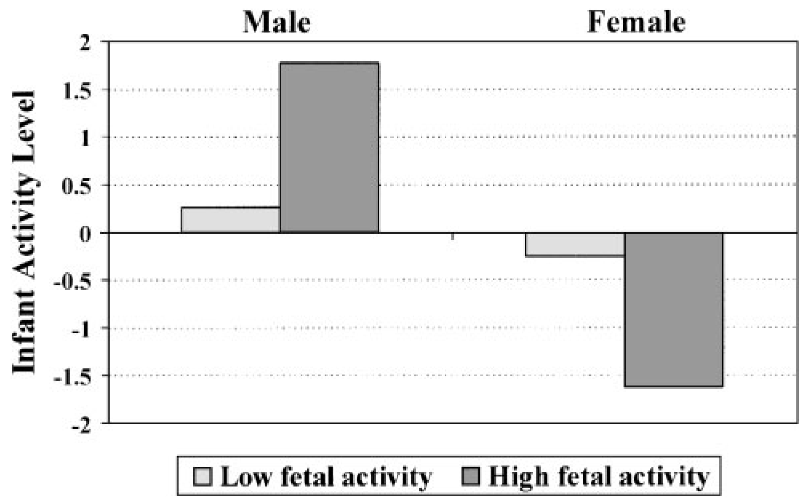

FIGURE 1 Mean values for Activity Level at 1 year (*Z* scores) by high and low levels of fetal Activity Level at 36 weeks, stratified by sex.

for between 21 to 37% of the variance. Significant, negative associations exist with each fetal measure at each gestational age, with the exception of two of these (24-week Activity Level and 36-week Bouts); those associations are of smaller magnitude, but in the same direction. Figure 2 displays the raw data for fetal Activity Level, averaged over the three gestational periods, plotted against Inhibition to allow examination of the consistency in these relations.

There is similarity between the predictive relations from the fetal period to Distress to Limitations at 1 year and Behavioral Inhibition at 2 years. These attributes were themselves positively, but only marginally, correlated, $r(27) = .34$, $p = .07$. In the event these relations were somehow artifacts of the slight differences in samples at each age, correlations were computed between Inhibition and Distress for only children that participated in both visits ($n = 29$). The pattern of correlation coefficients was essentially unchanged from those presented in Table 6.

Activity Level. TBAQ ratings of activity level displayed a trend towards a sex difference, $t(32) = 1.87$, $p = .07$, with boys again being more active. To evaluate the validity of this maternal report, infant laboratory observed Activity Level at 1 year was analyzed in relation to maternal report at 2 years. The correlation was significant, $r(26) = .36$, $p < .05$, one-tailed. Fetal movement measures prior to 36 weeks' gestation were not significantly associated with toddler Activity Level, but fetal Activity Level at 36 weeks was, $r(32) = .32$, $p < .05$, one-tailed. The within-sex correlations were similar (*r*s = .35 and .22 for boys and girls, respectively).

DISCUSSION

In this study, we found that measures of fetal movement show evidence of stability prior to birth, predict little about neonatal assessment, but predict fairly robustly to aspects of infant and child temperament. Unlike the infant, the fetus cannot be seen, touched, handled, or heard. The degree of precision afforded in measurement of postnatal functioning far exceeds that capable for the fetus, and considering the degree of error introduced by measurement limitation and the peculiarities of the intrauterine milieu, *any* documentation of predictive relations between the fetus and infant merits notice. On the other hand, the amount of variance in postnatal outcomes accounted for from the prenatal period is important in considering the extent of these relations.

The emergence of stabilities in fetal movement, a prerequisite for consideration of these measures as trait characteristics, began by 30 weeks' gestation. This replicates a previous report (DiPietro et al., 1996b) in which stabilities of similar magnitude were reported beginning at 28 weeks; for example, the correlation for activity level from 28 to 36 weeks' gestation in that report was .47. Repeated measures conducted at 38 to 40 weeks' gestation suggest that stability continues to increase as gestation advances, with correlations greater than .8 at term (Groome et al., 1999).

Neonatal behavior, assessed with a standard neurobehavioral exam, was only weakly associated with fetal movement measures. None of the overall regressions was significant when fetal movement measures across the gestational period studied were entered

Table 6. Prediction of Distress to Limitations at 1 Year and Behavioral Inhibition at 2 Years From Fetal Movement Measures (*ns* = 35)

	Movement Bouts				Movement Amplitude				Activity Level			
	B	*SE*	*t*	*r*	B	*SE*	*t*	*r*	B	*SE*	*t*	*r*
Distress to limitations (1 year)												
24 weeks	−.02	.02	−.97	−.05	−.37	.14	−2.59*	−.42**	−.16	.07	−2.34*	−.36*
30 weeks	−.03	.02	−1.40	−.27	−.27	.08	−3.48**	−.56***	−.17	.05	−3.49**	−.60***
36 weeks	.00	.02	−.30	−.05	−.17	.07	−2.30*	−.38*	−.11	.08	−1.36	−.24
Total model	Mult $R = .31$; $R^2 = .09$; $F(3, 30) = 1.04$				Mult $R = .65$; $R^2 = .43$; $F(3, 30) = 7.46$***				Mult $R = .66$; $R^2 = .43$; $F(3, 28) = 7.08$***			
Behavioral inhibition (2 year)												
24 weeks	−.04	.02	−2.37*	−.38*	−.19	.09	−2.02*	−.33*	−.07	.04	−1.61	−.28
30 weeks	−.03	.01	−3.38**	−.51**	−.08	.05	−2.07*	−.34*	−.07	.03	−2.06*	−.39*
36 weeks	−.02	.01	−1.60	−.27	−.13	.04	−2.96**	−.46**	−.11	.05	−2.11	−.35*
Total model	Mult $R = .61$; $R^2 = .37$; $F(3, 31) = 6.14$**				Mult $R = .54$; $R^2 = .30$; $F(3, 31) = 4.37$**				Mult $R = .45$; $R^2 = .21$; $F(3, 29) = 4.45$*			

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

together. Individual gestational-age-based associations were sporadic at best: Associations at only one age for each fetal movement predicted the three neonatal measures. This inconsistent pattern underscores the value of collecting data at multiple times during the antenatal period to avoid overinterpretation of results that may be spuriously generated at a single gestational age. Even in significant associations, shared variance was limited. Thus, although a significant association was detected between 36-week fetal movement and neonatal irritability, at best these data provide only minimal support for prior studies that documented associations between higher fetal motor activity and early infant irritability (DiPietro et al., 1996b; St. James-Roberts & Menon-Johansson, 1999). Similarly, while significant positive relations were found between aspects of neuromuscular development (Scarf Sign and Motor Development) and fetal movement amplitude, these associations were small.

There are several possibilities as to why we failed to detect relations over the relatively short time interval of 18 weeks from the initiation of fetal monitoring to the neonatal exam. First, despite its use with full-term infants by other investigators, the neurobehavioral assessment used was developed for preterm infants and may not be truly appropriate for assessing motor development in full-term infants. We doubt this because the components of the exam in general, and the motor cluster in particular, are common to other neonatal assessments. Second, assessment of neonatal performance is notoriously influenced by many situational factors, as demonstrated by the high correlation between infant state and the motor cluster. It is possible that these sources of error conspired to produce a preponderance of unshared variance. Third, the large *SD*s for each fetal movement measure illustrate the high level of interindividual variability, which tends to be the rule in studies of fetal movement (deVries, Visser, & Prechtl, 1988; Groome et al., 1999; Patrick, Campbell, Carmicheal, Natale, & Richardson, 1982; Roodenburg et al., 1991). This raises the possibility that the relatively limited range of the neonatal behavioral repertoire measurable by a single observation may be too restricted relative to the large interindividual variance in fetal movement behaviors. Fourth, some have failed to find stability in activity level from the neonatal period to later ages, and suggest that the nature of the motor behaviors exhibited in the neonatal period are not continuous with later forms of activity level (McBride-Chang et al., 1996). In the current study, scores on the neonatal Motor Development and Vigor cluster were unrelated to 1-year motor development, $r(30) = -.05$, and 1-year, $r(28) = .10$,

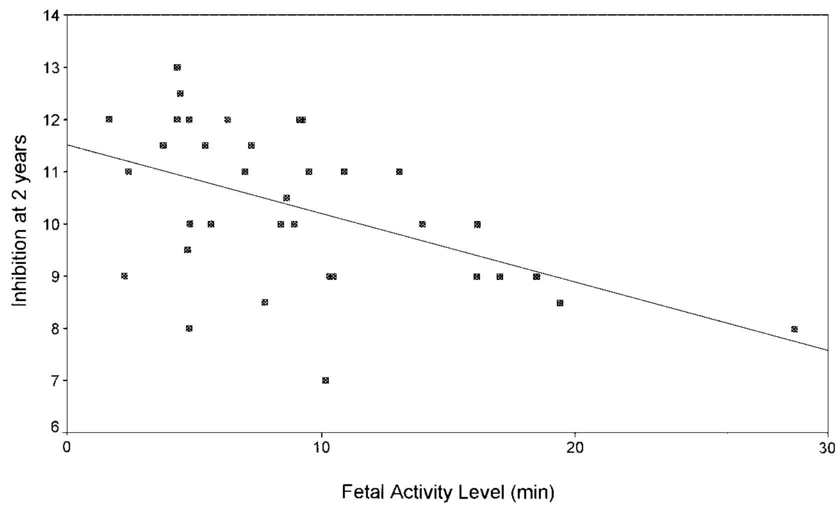

FIGURE 2 Fetal Activity Level, averaged over 24, 30, and 36 weeks of gestation, plotted against behavioral Inhibition at 2 years. Pearson correlation without outlier on right $r(32) = -.45$.

and 2-year, $r(27) = -.19$, activity level. The two studies which have successfully demonstrated individual stabilities in movement from the fetal to neonatal periods (Almli et al., 2001; Groome et al., 1999) relied on specific motor behaviors (i.e., leg and generalized body movement, respectively) exhibited during sleep. Stability in activity level in older children also is more likely to be detected when the same measures are used in the same situations (Fagot & O'Brien, 1994).

Does motor activity demonstrate stability from the prenatal to postneonatal period? Based on these data, we believe the answer is a qualified "yes" and that these relations begin late in gestation, consistent with the period in which fetal movement achieves stability. At 1 year, the positive correlations for boys between 36-week activity level was relatively high ($r = .45$), but only marginally significant as a result of the reduced power of the subgroup analyses. The correlation between 36-week fetal activity level and 2-year activity level was moderate, but significant ($r = .32$) for the sexes combined. Although a correlation of this size indicates only 9% of the variance is shared between fetal and toddler activity level, this is comparable to levels of associations interpreted as stability during relatively short age spans in infancy or childhood (Fagot & O'Brien, 1994; McBride-Chang et al., 1996). For example, the magnitude of the correlation for observed activity level from 3 to 9 months of age has been reported as .28 (Rothbart, 1986). Given the intrauterine constraints on fetal motor activity and difficulties in detecting fetal movement, the documentation of some degree of stability from the fetal period across the first 2 years of life is encouraging.

Attempts to ascertain predictive relations between fetal and infant activity level are strongly confounded by infant sex as demonstrated by the consistent and robust series of Sex × Movement interactions with each fetal measure. This effect is most pronounced at 36 weeks, at which time the number of fetal movements and activity level were positively associated with infant activity for boys but negatively related for girls. A recent study of state-specific, fetal to neonatal consistencies in leg movements found large differences in direction of correlations by sex; however, associations were *positive* for girls but *negative* for boys (Almli et al., 2001). Both the previous and the current studies are limited by small samples when stratified by sex ($ns = 9$ and 12, and 19 and 14, respectively). In older children activity level appears to be more stable and less influenced by situational factors for boys than for girls (Fagot & O'Brien, 1994; Halverson & Waldrop, 1976), and high activity during the toddler period predicts later problem behaviors for boys but not girls (Fagot & O'Brien, 1994). Moreover, it has been hypothesized that sex differentials in the rate of maturation contribute to sex differences after birth (Eaton & Yu, 1989), thus generating expectations of different patterns of associations for boys and girls over time. Using a structured regression approach to investigate the mediating and moderating role of maturation, the authors concluded that the overall accelerated maturation observed in girls is partly responsible for sex differences in activity level and that the relation between maturation and activity level in childhood differs by sex. Applying this logic to the current study, differences in the manner in which girls responded to the laboratory setting may have differentially affected their locomotor activity. Thus, high and low levels of activity as assessed in this study at 1 year may have different intepretations for boys and girls. No sex difference in associations was found at age 2, we suggest that this is a function of the use of maternal report at this age insofar as it is based on broad exposure to the child in multiple contexts.

With respect to the role of fetal sex in general, most documented sex differences reflect a relatively small mean difference and are concentrated in the tails of the distributions (Jacklin, 1981); thus, they are highly susceptible to vagaries of small samples, particularly where there is high within-sex variability, as is the case with fetal movement. Given the inconsistency in reports of antenatal sex differences, we conclude at this time that the high within-sex variability of fetal movement requires much larger longitudinal samples than currently exist to clarify the presence or absence of sex differences in movement prior to birth.

The most striking and consistent findings were the prediction of infant temperament at 1 and 2 years from fetal movement measures. These relations were largely consistent in direction and magnitude across all gestational periods and were similar for both 1-year Distress to Limitations and 2-year Behavioral Inhibition. Putting these relations in descriptive terms, individuals who were more active in utero displayed less distress to frustration and restraint at the first age and were more likely to interact with toys and the experimenter independently from their mothers at the later age. With the exclusion of the single nonsignificant relation between Movement Bouts and Distress to Limitations, the amount of variance accounted for from fetal movement measures alone in predicting these temperament characteristics was large, ranging from a low of 21% to a high of 43%. Because the child measures were positively correlated with one another, it is likely that these temperament measures share an underlying construct. Most apparent is that of regulatory control, the ability of children to modulate their behavior in an adaptive way to environmental challenges (Rothbart & Ahad, 1994). Why would high fetal movement be a forerunner of aspects of regulatory control in early childhood? In general, understanding of the trajectory of development of motor activity during the prenatal period is not as complete as that of other aspects of fetal neurobehavior, such as heart rate, in part because of methodologic inconsistencies in definitions (ten Hof et al., 1999). General body movements increase from the early fetal period of the midpoint of pregnancy (deVries et al., 1988), but decline after this time (Roodenburg et al., 1991). We observed a similar decline in two measures of fetal movement. However, little is known about the developmental course of sympathetic versus parasympathetic activation in stimulating and inhibiting motor activity in the fetus. If fetal maturation is associated with increasing levels of cortical control over motor activity, one would deduce that individual differences reflecting less fetal movement near term would represent more optimal neural development. Such a relation was detected in our prior study (DiPietro et al., 1996b), although it was based on maternal report measures of temperament that extended only through 6 months. The current results do not support such a supposition, and instead indicate that higher levels of fetal activity are associated with aspects of the developing nervous system that contribute to better regulatory processes in later childhood. These findings are reminiscent of those supporting the ‘‘inversion of intensity’’ hypothesis, in which intensity of motor behavior early in life negatively predicts behavioral intensity beginning in the second year as children develop strategies to regulate their levels of arousal (Bell, Weller, & Waldrop, 1971; McBride-Chang et al., 1996). The current findings also are consistent with the clinical view that fetal motor activity is a primary indicator of fetal well-being as gestation advances (Rayburn, 1990). It is possible that a curvilinear relation exists which we did not detect, such that both hyper- and hypoactivity levels are inoptimal during the fetal period, but the distribution of the data displayed in Figure 2 appear predominantly linear.

As a final methodologic note, we used three measures of fetal movement, although two of them (Amplitude and Activity Level) were highly correlated. Although both contributed to the prediction of temperament outcomes in similar ways, this was not the case for neonatal measures, for which amplitude was somewhat better associated. Amplitude is a function of the vigor with which a fetus moved and may be most related to local neuromuscular maturation. However, in general, activity level and amplitude are related in ways that suggest they reflect the same underlying dimension of fetal movement. Because both measures include brief and weak movements as well as larger and more sustained ones, they require the use of either a fetal actograph or ultrasound visualization. In contrast, the measure of movement bouts, which is most comparable in spirit to maternal fetal movement counting because it is a discrete variable, was associated with some aspects of temperament but not others. Until we know more about fetal movement development, multidimensional assessment remains a useful strategy.

This study is the first to document an association between prenatal motor activity and temperament and stability between prenatal and postnatal activity level across the first 2 years of life. It is not without limitations, most notably related to power in general and with respect to examining effects of sex in moderating relations over time in particular. This constraint led us to rely on less complex methods of analysis rather than higher level modeling techniques which could contribute important information involving individual trajectories before birth. Also, this study does not consider the role of maternal factors that operate on the fetus and may alter the relation between prenatal and postnatal function. An integrated approach to these issues, which requires a larger sample, more antenatal data points, and a multivariate approach, is currently under way in our laboratories. Nonetheless, the results from this exploratory study contribute to a better developed framework for understanding the significance of fetal motor activity to postnatal life.

NOTES

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