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Prenatal origins of temperamental reactivity

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Abstract

Background—Temperament theory has long considered individual differences in reactivity and regulation to be present at birth. Recent evidence suggests that such differences may be present prenatally and moderated by maternal emotionality.

Aims—To determine whether induced maternal emotional activation generates a fetal response and whether observed fetal responsivity is associated with early infant temperament.

Study Design—Women viewed an emotionally evocative labor and delivery documentary at 32 weeks gestation while physiological indices were evaluated and their infant's temperament was assessed at 6 weeks postnatal age.

Subjects—Participants were 137 pregnant women and their infants.

Outcome Measures—Maternal physiological (heart rate and skin conductance) and fetal neurobehavioral (heart rate and motor activity) data were collected during gestation in response to the stimulus. Infant temperament (irritability and consolability) data were based on observational methods after birth.

Results—Fetuses reacted to maternal viewing of the video with decreased heart rate variability, fewer motor bouts, and decreased motor activity. There was correspondence between the nature of individual maternal physiological responses to the full video, as well as phasic responses to a graphic birth scene, and fetal responsivity. Fetuses that reacted more intensively to maternal stimulation were significantly more likely to become infants that demonstrated greater irritability during a developmental examination at 6 weeks of age.

Discussion—These results support the presumption that *early postnatal temperamental characteristics* emerge during the prenatal period.

Introduction

“The history of man for the nine months preceding his birth would, probably, be far more interesting and contain events of greater moment than all the three score and ten years that follow it.” Samuel Taylor Coleridge (1885)

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Speculation on the foundations of human development has long been a topic of folklore, literature, and philosophy. Consideration of variation in balance among elements within the body as being the core of individual differences suffused ancient Western and Eastern philosophies. Contemporary scientific literature defines temperament as defined as stable, biologically based individual differences in reactivity and regulation that form the core of personality (1). Reactivity refers to the arousability of behavioral, endocrine, and nervous system responses, while regulation involves processes such as attention, approach, avoidance, and inhibition that serve to decrease or increase reactivity (2). Variation across these dimensions is assumed to be present at birth (3) and has been shown to persist with relative stability across time (4–6).

A small number of studies has shown that individual differences in temperament begin before birth. Aspects of baseline fetal motor activity have been associated with maternally reported early infant crying patterns (7) and temperament through 6 months (8), as well as more objectively measured outcomes such as behavioral inhibition at age 2 (9). Preservation of individual differences from the fetal to infant periods has been reported for state behavior (10,11), facial expressiveness (12), and spontaneous motor activity (9,13).

Most infant temperament paradigms involve scenarios designed to invoke behavioral reactivity and regulation to better address the core constituents of individual differences, but the fetus seems beyond the reach of such experimental methods. In fact, fetal responsivity can be elicited by alterations to the uterine environment. Anecdotal observations of fetal reactivity to acute maternal distress have been reported in the academic literature for many years (14–16) and the topic has been systematically studied in a small number of investigations. One of the first reports described fetal tachycardia in response to a maternal startle induced by dropping a metal container on a tile floor simultaneous with a camera bulb flash (17). In non-human primates, presentation of relatively minor psychological stressors to the mother generated changes in fetal heart rate, blood pressure, and arterial oxygenation (18,19).

More recently, a number of studies have relied on the Stroop color-word test, a cognitive challenge, to evoke maternal activation. The broader context of this work is to investigate the manner in which maternal *emotions* may be physiologically transduced to the fetus, thereby potentially altering the intrauterine environment and exerting more persistent influences on shaping development prior to birth. Fetal motor suppression coupled with increased cardiac variability in response to induced maternal stress using this paradigm have been shown at two gestational ages with evidence of stability in individual maternal and fetal response patterns over time (20). The degree and nature of the fetal heart rate response to this challenge appear to be moderated by maternal psychological characteristics (21,22).

The aims of the current study were twofold. *The first was to examine the degree to which there was correspondence between induced maternal physiological arousal, evoked by an emotionally charged and contextually appropriate stimulus – viewing of a labor and delivery documentary – and fetal neurobehavioral reactivity. The second was to ascertain whether observed fetal responsiveness to maternal stimulation might serve as an early marker of emerging individual differences in temperamental reactivity and regulation.* Thus, we examined continuity in the nature of an individual's evoked reactivity from the fetal period, during which time stimulation is mediated by the pregnant woman, to the early infant period, during which reactivity was directly elicited from the infant. We predicted that highly reactive fetuses would become highly reactive infants, and fetuses with low reactivity would become less reactive infants.

Methods

Participants

Eligibility was restricted to non-smoking women at least 20 years old with singleton, uncomplicated pregnancies with consistent pregnancy dating who gave birth to healthy infants.

Prenatal procedure

The study was approved by the local Institutional Review Board and all participants provided informed consent. *During the 32nd gestational week*, 30 minutes of baseline recording of maternal physiological and fetal neurobehavior were followed by a 29 minute labor & delivery video (*Birth Stories*, The Cinema Guild, NY). *The video included a variety of women recounting the events and their feelings surrounding their children's births, interspersed with graphic delivery scenes in black and white, thereby eliciting a wide variety of emotions, both positive and negative, regarding the birth experience.* Women were monitored in a semi-recumbent, left-lateral position and viewed the video without companions, wearing headphones. The first birth scene occurred 10 min into the beginning of the recording and lasted for 23 s. The onset of this episode was electronically marked in the computer file to provide analysis of a phasic response to a brief, but intense, stimulus.

Maternal-fetal monitoring—Maternal and fetal data were simultaneously digitized at 1000 Hz using an A/D board and streaming software. Maternal physiological signals were amplified by an electrically isolated bioamplifier (James Long Company, Caroga Lake NY). Electrocardiogram (ECG) was recorded from 3 carbon fiber disposable electrodes in triangulated placement (right mid sub-clavicle, left mid axillary thorax, and upper left thigh for ground lead). ECG data underwent R-wave detection, manual editing for artifact, and interbeat interval (IBI) computation. To maintain comparability to fetal measures, IBI values were converted to heart rate (HR). Respiration was derived from a bellows apparatus stretched across the ribcage below the breasts. Respirations were measured by quantifying inspiration to inspiration and expiration to expiration periods based on the detected peaks and troughs of the respiratory waveform. Respiratory period values correspond to the number of seconds between each breath. Electrodermal activity was monitored from two Ag/AgCl electrodes with a gelled skin contact area placed on the distal phalanges of the index and second fingers of the non-dominant hand affixed with adhesive collars to limit gel contact to a 1 cm diameter circle, and velcro. Skin conductance level (SCL) was measured by administering a constant 0.5 volt root-mean-square 30 Hz AC excitation signal and detecting the current flow and scaled from 0 to 25 microsiemens. This measure reflects changes in conductivity of the skin as modulated by eccrine glands that are sympathetically activated (23).

Fetal data were collected from the output port of a Toitu (MT320) fetal actocardiograph. This monitor detects fetal movement and fetal heart rate through a single, wide array transabdominal Doppler transducer and distinguishes each from one another and competing signals through band-pass filtering. Reliability studies comparing actograph based versus ultrasound visualized fetal movements have found the performance of this monitor to be highly accurate in detecting both fetal motor activity and quiescence (24,25). Digitized heart rate data underwent error rejection procedures based on moving averages of acceptable values as needed. Fetal variables included two cardiac measures: fetal heart rate and variability (root mean square) of each 1-min epoch aggregated over time. Fetal movement was based on the actograph signal, which ranges from 0 to 100 in arbitrary units. A movement bout was identified when the first spike of the actograph attained amplitude of 15 units and concluded with cessation of 15 unit signals for at least 10 s. Two fetal movement variables were derived: the number of bouts and total motor activity, computed as the number of bouts multiplied by the mean movement duration, which reflects the amount of time the fetus spent moving (s).

Maternal psychological response—Women rated their emotional responses to the video at its completion on 5-point scales along the following dimensions: enjoyable, heart-warming, uplifting, stressful, and anxiety-provoking. The first three were collapsed into a positive rating; the latter two into a negative rating.

Postnatal procedure

Infants participated in a laboratory procedure at 6 weeks postpartum (M days = 45.5, SD = 3.4) designed to elicit negative reactivity. Infants underwent a series of maneuvers based on a standard infant developmental assessment that included: 1) evaluation of initial state; 2) ventral suspension; 3) supine placement; 4) prone placement; and 5) ring tracking, followed by 6) undressing; 7) weighing; and 8) redressing. The procedure was videotaped and then scored as to whether or not the infant cried during each of the segments; irritability scores could range from 0 to 8. A subset of 20 tapes was dually scored; reliability, as assessed by κ , was 1.0. Infant unconsolability was scored on a 4-point scale ranging from not irritable enough to require consoling through not consolable and still fussy at end of procedure (κ = .93). Coders and the examiner were unaware of fetal values. The follow-up protocol was not instituted until after 16 infants had been born due to delay in laboratory renovation. Of the remaining participants, 102 (84%) participated. There was a trend for older women to bring their infants in for testing, $t(119) = 1.90$, $p = .06$, but no other differences were detected.

Data Analysis

All fetal and maternal measures were examined for normalcy. Maternal and fetal data collected during the baseline period were compared to values recorded during the entire video using repeated measures analysis of variance (ANOVA), as were phasic changes from the 90 s periods immediately preceding and following the onset of the first graphic birth scene. A slightly different measure of fetal motor activity, based on the continuous signal and not bout counts, was necessary for the latter analysis given the brevity of the interval. Individual change scores were computed to determine the degree to which the magnitude of the maternal physiological and fetal responses were correlated, and evaluate associations between maternal psychological attributes and fetal responsivity. Associations between fetal and infant data were evaluated using ANOVA and *Spearman correlations*. *Effect sizes (η^2)*, which provide indication of the strength of detected associations, were calculated for each *F*-value. The potential moderating role of maternal parity was evaluated by testing for interactions.

Results

Maternal and child characteristics

A total of 159 women participated in the video viewing protocol; 22 were either prospectively or retrospectively from data analysis as follows: preterm labor, preterm delivery, or both (13; 8%); gestational diabetes (2; 1%); congenital malformation (1; <1%); and growth retardation or other condition of antepartum origin detected in the newborn (6; 4%), resulting in a final sample of 137 participants. Participants tended to be well educated (M = 16.7 years, SD = 2.1), mature (M age = 31.3 years; SD = 4.1), and married (94%). This was the first pregnancy for 55%, and 50% of the fetuses were male. Fifteen percent of the sample was of an ethnic or racial minority, with African-Americans comprising the largest proportion of minority participants (13%). Infants were delivered at term (M weeks gestation = 39.4 weeks, SD = 1.2) and were of normal birth weight (M = 3520 g; SD = 440) with appropriate 5 minute Apgar scores (M = 8.9, SD = .5).

Maternal response to video

The video could not be shown to one participant due to technical problems, reducing sample size to 136. Most women (86%) reported that they had previously seen a birth video, and perceived the study video to be more heartwarming and uplifting than stressful or anxiety provoking, $t(134) = 12.21, p < .001$. In general, women responded with significant decreases in heart rate and respiratory period, indicating faster breathing, and an increase in SCL (Table 1). Various sources of artifact generated missing values for each maternal measure during the baseline and/or video segments. These include cardiac arrhythmia ($n = 1$) for maternal heart rate, transducer fault ($n = 4$) for SCL, or difficulties in detecting an adequate respiratory signal using the bellows apparatus due to the pregnant body habitus ($n = 21$). There were no significant interactions suggestive of differences in maternal responses based on parity (first pregnancy versus all subsequent).

Tonic fetal response to video

Poor signal quality eliminated fetal HR analysis in one case, and fetal movement analysis in two cases. Table 2 presents means for fetal neurobehavioral measures before and during the video. Fetal HR was unchanged, but variability decreased in response to the video. Because the baseline period was about 1 min longer than the stimulus period, the number of fetal movements during the video was prorated to equalize duration. Fetuses displayed fewer motor bouts during the video than before it.

Association between individual maternal and fetal responses

Change scores were created by subtracting video values from baseline values; thus positive and larger change score values indicate greater decrements for each variable. The degree of maternal HR response to the video was correlated with changes in fetal HR, $r(133) = .20, p < .05$, motor bouts, $r(132) = .18, p < .05$, and motor activity, $r(132) = .20, p < .05$. Fifteen percent of the viewers ($n = 21$) cried during the most moving parts of the video; *logistic regression indicated that the decline in fetal HR, controlling for initial level, was greater in that group (Model $\chi^2(2, N=135) = 7.26, p < .05$). Change in SCL and respiratory period were unrelated to changes in fetal measures.*

Phasic maternal and fetal responses

Sufficiently artifact-free data during the 180 s of this analysis were available for 128 women. Women responded to the first graphic birth scene with an immediate decrease in HR, $F(1,127) = 12.82, p < .0001; \eta^2 = .092$ and surge in SCL, $F(1,127) = 7.01, p < .01; \eta^2 = .052$. Sufficiently artifact-free data were available for 128 fetuses for HR data and 127 fetuses for movement data. Although there was no typical fetal response during this period, there was correspondence between maternal-fetal reactivity within individual pairs. Maternal HR change was correlated with fetal HR change, $r(126) = .19, p < .05$ and the maternal SCL response was associated with change in fetal variability, $r(126) = .23, p < .01$, and fetal motor activity, $r(125) = .31, p < .001$. While there were no differences in maternal HR or SCL in response to the birth scene based on parity, fetuses of women who had not given birth before responded with increased fetal motor activity, in contrast to reduced activity among those that had, $F \text{ interaction}(1,125) = 4.73, p < .05, \eta^2 = .036$.

Maternal response patterns and fetal reactivity

Maternal response patterns to *both the full video and initial graphic scene* were further examined by constructing a single measure to characterize reactivity in both cardiac and electrodermal domains based on rudimentary attentional (i.e., decreased HR) and arousal (i.e., increased SCL) responsivity. Assignment to one of four cells was based on deviation from no (zero) change, and include: HR decrease/SCL increase (describing 55% and 30% of

participants during the full and phasic periods, respectively), HR decrease/SCL decrease (21% and 34%); HR increase/SCL increase (20% each segment); and HR increase/SCL decrease (4% and 16%). ANOVA results revealed significant associations with fetal motor reactivity for both sets of analyses. For the full video period, maternal response patterns were significantly associated with change in fetal motor bouts, $F(3, 126) = 3.13$, $p < .05$; $\eta^2 = .069$. Post hoc Fishers LSD comparisons revealed that fetuses of women demonstrating physiological responses consistent with low attention to the stimulus but high physiological arousal (HR increase/SCL increase) reacted with motor activation as opposed to the motor suppression observed in the other groups (Figure 1). All of the 5 women displaying a paradoxical response (low attention, low arousal) were nulliparous; fetuses of this small group showed the greatest motor suppression. During the phasic analysis, the finding for fetal movement was of similar magnitude, $F(3, 123) = 3.06$, $p < .05$, $\eta^2 = .069$, and again motor activation accompanied a pattern suggestive of low attention but high physiological arousal (not shown).

Associations with early infant temperament

Infant irritability values ranged from 0 to 5, $M = 1.29$, $SD = 1.61$, and unconsolability values ranged from 1 to 4, $M = 2.53$, $SD = 1.12$. These behaviors were correlated, $r_s(99) = .70$, $p < .0001$. Neither was significantly associated with postpartum age, infant sex, or breastfeeding status (75% of infants were exclusively breast-fed). Associations between fetal change scores from the baseline to video period and infant behaviors are presented in Table 3. *Phasic fetal responsivity to the birth scene was unrelated to infant measures.*

Over a third (38.7%) of infants did not cry at all during the procedure, so analyses were also conducted for a dichotomized irritability measure (cry/no cry). Repeated measures analysis testing for an interaction term between irritability category and fetal response to the video indicated significant interactions for each of the four fetal measures including: HR, $F(1, 98) = 4.89$, $p < .05$, $\eta^2 = .048$, variability, $F(1, 98) = 4.02$, $p = .01$, $\eta^2 = .039$, motor bouts, $F(1, 97) = 4.84$, $p < .01$, $\eta^2 = .048$, and motor activity, $F(1, 97) = 8.84$, $p < .01$, $\eta^2 = .084$. In each instance, fetuses that became irritable infants reacted to the video with greater suppression in each variable. In addition, a main effect was observed for fetal HR; fetuses with slower HR both before and during the video were more likely to be in the irritable infant category, $F(1, 98) = 5.95$, $p < .05$; $\eta^2 = .057$. Fetal heart rate and motor activity results are illustrated in Figure 2.

Discussion

The labor and delivery stimulus used in this study was an effective elicitor of a multidimensional maternal physiological response with evidence of both sympathetic (elevated skin conductance, faster respiration) and probable parasympathetic (lowered heart rate) activation, consistent with dual mechanisms of emotional arousal and attention (26). While it appears that the manipulation also elicited a fetal response, consisting of suppression of individual motor bouts, overall motor activity, and variability in heart rate, such a conclusion must be tempered by the lack of a control condition that would more explicitly test the fetal group effect. The observed motor suppression to a maternal manipulation supported our expectations based on response patterns to the Stroop cognitive stressor but are in contrast to the previously observed increase in heart rate variability (20).

A number of the findings linking maternal and fetal responsivity illustrate the importance of the maternal psychological context. Most women regarded the birth film as a positive affective experience yet the phasic fetal response to the graphic birth scene differed between women who had not given birth before; thus the transient surge in fetal activity of primiparous women may reflect greater maternal alarm to this image. Because there are no direct neural or circulatory connections between the mother and fetus, fetal responses generated by maternal stimulation require some degree of transduction. A number of significant maternal-fetal

associations were detected. Maternal HR responsivity to the full video was significantly associated with fetal HR and motor responses, such that greater maternal HR suppression was associated with greater fetal HR and motor suppression. Moreover, there was evidence that maternal autonomic response patterns affected fetal responses, such that fetuses of women who mounted what might be interpreted as a defensive response (increased HR and SCL) showed increased motor activity in contrast to other groups. During the phasic stress period, maternal SCL changes were also associated with changes in fetal HR variability and motor activity such that fetuses of women who responded with larger elevations in SCL exhibited increased fetal motor activity and HR variability. Because electrodermal activity is singly innervated by sympathetic processes, this suggests closer linkage between maternal-fetal sympathetic activation in the short-term.

However, the magnitudes of detected associations between maternal and fetal responses were relatively small and other information suggests that correlational associations between maternal and fetal measures do not necessarily imply a causal influence (27). Existing data, which indicate links between maternal anxiety and blood flow through the umbilical artery (28), correlations between maternal and fetal cortisol levels (29), and decreases in arterial oxygenation in response to psychological stressors in animal preparations (18) provide other potential mechanisms that were unmeasured in this study. We offer another possibility: that the fetal response was elicited by sensory-based alterations in the intrauterine milieu. Fetal heart rate responses have been observed within seconds of disruption of the maternal environment in investigations of prenatal sensory capacities, including maternal postural changes (30) and auditory stimuli (31). A similarly rapid onset of a fetal response to induced maternal psychological stress, including increased fetal heart rate variability, has been reported in non-human primates, leading to the suggestion that fetal response represents detection of alterations to the intrauterine sensory environment (32). Maternal vasculature and digestive sounds are prominent in the uterine auditory environment (33) and it is possible that sudden accelerations or decelerations in maternal heart rate and accompanying blood pressure and gastric motility changes may provide the fetus with a changing uterine sensory environment, thereby eliciting a fetal orienting response, consistent with the observation of suppressed cardiac variability and motor activity observed here.

The results generated by this study provided *preliminary support* for the prenatal emergence of *early infant temperament*. *Associations were modest in magnitude but consistent in direction and across fetal domains*. For each of the four fetal measures, fetuses that showed greater reactivity to maternal stimulation were more likely to be irritable to the infant procedure. *In addition, the directionality of the fetal autonomic and motor response – suppression or augmentation – also predicted infant irritability*. Associations with consolability were not as consistent; however, the fetal protocol did not have a comparable period during which to assess regulation following maternal stimulation *which would perhaps have provided more comparability in the assessment of self-regulation*. Nonetheless, fetuses that showed greater motor activity reactivity were also more likely to be less consolable infants. The two dependent measures of temperament used in this study were basic but addressed the core facets of infant temperament. *Although the amount of shared variance between fetal and infant measures was relatively small, the vast differences in contexts in which the fetus and infant were measured coupled with the necessity to operationalize the construct of reactivity differently at each developmental period suggests that the actual degree of prenatal to postnatal consistency in reactivity may be underestimated*.

Little is known about whether the frequency or nature of maternal response patterns during pregnancy might sculpt the developing fetal nervous system over the course of gestation. There is preliminary evidence that activity in other biological systems, including the prenatal maternal hypothalamic-pituitary-adrenal axis, has persistent effects on temperament in infancy (34,

35). These results suggest that included among the latter may be physiological and contextual signals provided to the fetus in utero by variation in maternal responsivity to demands present within her own environment.

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Figure 1.

Fetal motor bout suppression in response to maternal video viewing distributed by maternal attention/arousal categories. Higher values indicate greater suppression. Significant differences between third group and all others.

Figure 2.

Change in fetal heart rate (a) and fetal motor activity (b) categorized by infant irritability to laboratory procedure. Significant interactions were found for each of four fetal measures; fetuses that showed heart rate and motor activity suppression to maternal arousal were more likely to become irritable during neonatal testing; fetal heart rate and activity augmentation was associated with lack of neonatal irritability.

Table 1

Maternal response to labor and delivery video

	Baseline <i>M</i> (<i>SD</i>)	Video <i>M</i> (<i>SD</i>)	<i>df</i>	<i>F</i> -value	η^2	<i>p</i>
Heart Rate (bpm)	88.34 (11.00)	86.42 (10.78)	1,134	65.06	.327	.0001
Skin Conductance Level (μ S)	7.29 (3.38)	8.36 (3.94)	1,131	65.17	.332	.0001
Respiratory Period (s)	4.15 (1.01)	3.63 (1.18)	1,114	8.13	.067	.005

Table 2

Fetal response to labor and delivery video

	Baseline <i>M</i> (<i>SD</i>)	Video <i>M</i> (<i>SD</i>)	<i>df</i>	<i>F</i> -value	η^2	<i>p</i>
Fetal heart rate	141.03 (6.63)	140.63 (6.60)	1,134	.96	.007	-
Fetal heart rate Variability	7.10 (2.07)	6.59 (2.09)	1,134	8.66	.061	.005
Number of movements	36.28 (10.06)	30.97 (10.93)	1,133	20.09	.131	.0001
Total time moving (s) [§]	459.84 [§] (316.59)	409.54 (315.27)	1,133	4.04	.029	.05

[§]Untransformed values; data analysis performed on values transformed for normalcy.

Table 3
Spearman correlations (r_s) between fetal and newborn measures (n = 100)

	Irritability	Newborn measures Consolability
Fetal responsivity		
Heart rate	.22 [*]	.09
Variability	.21 [*]	.02
Motor bouts	.23 [*]	.13
Motor activity	.24 [*]	.27 ^{**}

*
 $p < .05$;

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 $p < .01$.