Maternal Stress Responses and Anxiety during Pregnancy: Effects on Fetal Heart Rate

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ABSTRACT: *This study examined the effect of an acute maternal stress response and anxiety on fetal heart rate. Seventeen healthy, 3rd-trimester pregnant women (mean age = 26 ± 6 years) were instrumented for continuous electrocardiography, blood pressure (BP), respiration, and fetal heart rate (HR). Subjects completed the state anxiety subscale of the State Trait Personality Inventory (STPI), then rested quietly in a semirecumbent position for a 5-min*

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baseline period, followed by either a 5-min arithmetic or Stroop color–word task. Over the entire 5-min stress period and when averaged across all subjects, the stressors led to significant increases in maternal systolic BP and respiratory rate but changes in maternal HR, diastolic BP, and fetal HR were not significant. However, when subjects were dichotomized into groups that had above or below average anxiety scores [ANX(+) and ANX(−)], both groups had similar respiration rate increases to the stressors, but the BP and fetal heart rate (FHR) responses were significantly different. Women in the ANX(−) group had significantly greater BP responses compared to women in the ANX(+) group whereas the fetuses of ANX(+) women showed significant HR increases and the fetuses of ANX(−) women exhibited nonsignificant decreases. These findings suggest that women's acute emotional reactivity during pregnancy can influence fetal HR patterns and that a stress-induced increase in maternal BP is not the primary signal by which a women's stress response is transduced to her fetus. The results are consistent with the hypothesis that maternal psychological variables may shape the neurobehavioral development of the fetus. Dev Psychobiol 36: 67–77, 2000

Keywords: *human fetus; heart rate; pregnant women; anxiety*

INTRODUCTION

Stress and anxiety during pregnancy are associated with significant risk of obstetric abnormalities. Prenatal life event stress repeatedly has been linked to lower birth weight and preterm birth (McCubbin et al., 1996; Sandman et al., 1994; Vallee, Mayo, Maccari, Le Moal, & Simon, 1996; Wadhwa, Sandman, Porto, Dunkel-Schetter, & Garite, 1993). When potentially confounding risk factors such as race, maternal age, marital status, education, tobacco, and alcohol use are controlled, life event stress remains a significant predictor of preterm birth and low birth weight (Copper et al., 1996). Increased anxiety also has been associated with premature birth (Davids & DeVault, 1962) and other neonatal risks such as low Apgar scores (McDonald, Gynther, & Christakos, 1963).

Overactivity of the maternal neuroendocrine system has been hypothesized to underlie the negative health outcomes of fetuses born to stressed or anxious mothers (Sandman et al., 1994; Wadhwa et al., 1993). Activation of the HPA axis may expose the fetus to elevated levels of hormones known to contribute to preterm labor and delivery (Sandman et al., 1994; Wadhwa, Dunkel-Schetter, Chicz-DeMet, Porto, & Sandman, 1996). In addition, stress and anxiety may precipitate the release of catecholamines, resulting in maternal vasoconstriction and consequent restriction of oxygen and nutrients to the fetus (Copper et al., 1996).

Experiments with animals suggest that maternal stress during pregnancy also has long-term effects on the offsprings' regulation of stress-induced changes in physiology and behavior. Offspring of rats exposed to an acute stressor (e.g., restraint) during pregnancy have elevated ACTH stress responses as preweanlings (Takahashi & Kalin, 1991) and prolonged stress-induced corticosterone secretion as adults (Vallee et al., 1996). Rats that experienced in utero exposure to stress (e.g., heat or restraint) tend to show anxious, fearful behavior as measured by increases in the number of escape responses to novelty (Williams, Hennessy, & Davis, 1996) and the number of ultrasonic vocalizations emitted during isolation (Vallee et al., 1997). Prenatally stressed rats exhibit a greater latency to play with other pups (Takahashi & Kalin, 1991) and, in monkeys, poorer motor skills and distractibility (Schneider, 1992; Schneider & Coe, 1993).

Recent studies with human infants are consistent with the animal data suggesting that maternal emotions during pregnancy may alter the offspring's neurobehavioral development, specifically the behavioral and physiological patterns associated with emotion regulation. Within just 24 hr of birth—prior to extensive caretaking—babies born to depressed women show signs of differences in central nervous system development. Newborns of depressed women were described as having less motor tone, activity, and endurance, and more irritability on a neurobehavioral exam (Abrams, Field, Scafidi, & Prodromidis, 1995; Field, 1995); however, the influence of maternal health behaviors during pregnancy was not investigated in these studies. In research based on over 1,100 women that did control for health behaviors, maternal depression was a significant predictor of newborn fussiness and nonsoothability (Zuckerman, Bauchner, Parker, & Cabral, 1990). In addition, state anxiety has been found to be positively correlated with more active and irritable neonatal behavior (Field, Sandberg, Quetel, Garcia, & Rosario, 1985), and maternal "Type A" behavior was associated with increased infant crying during a standardized neurobehavioral assessment (Parker & Barrett, 1992). Finally, similar to animal studies examining the sequelae of prenatal maternal emotions in

offspring regulatory physiology, Ponirakis, Susman, and Stifter (1998) found that a composite score of maternal trait anxiety—a personality characteristic typified by a propensity to feel anxious—and depression was associated with reduced high-frequency heart rate variability (HRV) in neonates. High-frequency HRV has been used as a measure of cardiac parasympathetic modulation (Porges, 1995; Porges, Doussard-Roosevelt, Portales, & Suess, 1994) and is suggested to be an index of the organism's capacity to self-regulate via appropriate autonomic reactivity (Huffman, Bryan, del Carmen, Pedersen, Porges, 1995 Doussard-Roosevelt, 1998).

Despite the converging evidence suggesting that maternal emotions during pregnancy affect fetal neurobehavioral development, few studies have directly measured fetal behavior as it is influenced by maternal physiology associated with emotion experience. In recent studies, DiPietro, Hodgson, Costigan, and Hilton (1996b) examined fetal variables in relation to maternal reports of life stress and resting heart rate. Mothers who reported greater stress and had higher resting heart rates (HR) had fetuses who showed a delay in the maturation of the coupling of HR and movement, hypothesized to be an index of immature central nervous system development (DiPietro, Hodgson, Costigan, & Johnson, 1996a). Overall, fetuses of pregnant women who reported greater life stress had reduced fetal HRV (DiPietro et al., 1996b). Other studies showing positive associations between pregnant women's emotion and fetal variables did not include measures of maternal physiology. Field et al. (1985) found that maternal anxiety was associated with maternal reports of increased fetal activity. On the other hand, Groome, Swiber, Bentz, Holland, and Atterbury (1995) found that maternal anxiety predicted lower gross body movement during active sleep and greater periods of quiet sleep in the fetus. Concurrent monitoring of maternal and fetal physiology while exposing the mother to an emotion-eliciting stimulus could help clarify the impact of maternal emotions on the fetus as well as elucidate the physiological pathways by which maternal emotional state and responses may alter fetal neurobehavioral development.

The aims of this study were to examine (a) pregnant women's physiology in responses to a standardized laboratory stressor, (b) fetal heart responses associated with an acute maternal stressor, and (c) the effect of maternal anxiety on these maternal and fetal heart rate responses. We concurrently monitored maternal and fetal physiology during a resting baseline and a cognitive challenge to test the hypotheses that during a mental stressor, maternal cardiorespiratory and fetal HR activity would increase in a manner indicative of sympathetic activation and/or parasympathetic withdrawal and that the maternal and fetal responses would be greatest in women identified as more anxious.

METHODS

Subjects

Through posted announcements and signs in obstetricians' offices, 20 pregnant, nonsmoking women with singleton fetuses ranging in gestational age from 35–38 weeks were recruited at the Columbia–Presbyterian Medical Center (CPMC). Women were excluded from the study if there were any maternal or fetal complications including hypertension, diabetes mellitus, suspected fetal growth restriction, or a fetal structural anomaly on ultrasound. Two women in the study reported taking iron pills for anemia. None of the subjects reported smoking while pregnant nor drinking more than two glasses of wine throughout the entire pregnancy. Sixty-five percent of the sample was Latina, 25% was Caucasian, and 10% was African-American. For all subjects, English was the primary language. The mean maternal age was 26 years ($\pm$6 years). Mothers' average education was 14 years (SD = 3.71, range = 9 to 23 years), 55% were married, 50% were primiparous, and 50% were working outside the home at least half-time. Because this sample was drawn from an urban hospital and included doctors and support staff as well as patients, average annual family income was above the national average yet included women receiving public assistance (M = \$66,000, SD = \$84,773, range = \$5,200 to \$300,000). This study was approved by the Institutional Review Board CPMC. Informed consent was obtained from each subject.

At the time of testing the average gestational age was 37 weeks (SD = 1 week, range 35–38 weeks) as determined by a combination of last menstrual period and sonogram. All fetuses were born after 37 weeks (M = 39 weeks, range = 37–42 weeks) and none was small for date. The average weight at birth was 3,567 g (SD = 512.2, range = 2,780–4,450 g).

Procedure

Women made a single visit to the laboratory that began at about 11 a.m. and ended at 1 p.m. After a review of the experimental procedures, they completed a self-report measure of state anxiety (STPI) (Spielberger, 1979) and were interviewed briefly about their pregnancy and living situation. Electrodes for electrocardiographic (ECG) and respiration monitoring then

were attached to their right shoulder, on the left anterior axillary line at the 10th intercostal space and in the right lower quadrant. Electrodes also were placed on the women's abdomen to record fetal ECG (discussed later). The subject then was placed in a semirecumbent position. A Finapres blood pressure (BP) cuff (Ohmeda) was placed on the middle finger of the nondominant hand and a numeric keypad for responding to the tasks was secured in a comfortable position relative to the dominant hand. Subjects could not see the keypad but could identify the keys by feel. An ultrasound transducer (Advanced Medical Systems) was placed on the subject's abdomen as an alternative method to record fetal instantaneous HR. BP readings from the Finapres were checked against a manual sphygmomanometer; adjustments in the Finapres cuff and nondominant hand position were made until the difference between the sphygmomanometer and Finapres readings was less than ±10 mmHg SBP. Subjects were given instructions regarding the cognitive tasks and were allowed to practice for 1 min. At the start of data collection, subjects rested quietly for a 5–min baseline. They performed either a mental arithmetic stressor or a Stroop color–word task, each 5 min in length and followed by a 3–min recovery period. Because most previous research has shown high correlations in cardiovascular reactivity to arithmetic and Stroop color–word tasks (Linden, Frankish, & McEachern 1985; Benschop et al., 1998), subjects were randomly assigned to either task. The subjects were instructed to remain silent throughout the procedures.

Cognitive Stressors

Mental Arithmetic. In this task, the subjects were presented with a four–digit number on a computer monitor and were instructed to subtract serially by seven starting with this number, which disappeared after the first answer was entered. Subjects entered their answers on the numeric key pad. At 1-min intervals, the experimenter gave the subject verbal prompts, e.g., "please work a little faster." This task was not paced by the computer, but the subjects were instructed to subtract as quickly and as accurately as possible.

Stoop Color–Word Task. In this version of the Stroop task, the subjects were presented with color names (blue, green, yellow, and red) in colored letters that were either congruent or incongruent with the names. The subject's task was to press the key on the keypad that corresponded to the color of the letters. The task was paced by the computer, and an incorrect response or failure to respond rapidly enough resulted in a message indicating "incorrect" on the screen. At 1-min intervals, the experimenter gave the subject verbal prompts, e.g., "please work a little faster."

Self-Report of Stress. The subjects were asked to rate the stress they experienced on a 1 (*none at all*) to 10 (*extreme stress*) scale after each period of the experiment.

Acquisition and Processing of Maternal ECG and Respiration Signals

Heart Rate and Respiration. Electrodes were attached to a heart/respiration rate monitor (Hewlett Packard 78292A) and the analog ECG and respiration impedance waveforms were digitized and collected by a microcomputer. Analog ECG signals were digitized at 500 Hz by a 16-bit A/D card (National Instruments 16XE50). Specially written software was used to mark R waves and create files of RR intervals. Artifacts in the RR-interval series were defined as values below 0.4 s (HR >150 bpm) or above 1.5 s (HR <40 bpm). When artifacts were detected, the RR-interval file was examined. Artifacts were rejected or corrected following established procedures (Berntson, Quigley, Lang, & Boysen, 1990). For respiration, postacquisition software was used to mark the peaks and troughs of the impedance waveform. These marks were verified by visual inspection and then were used to calculate respiratory rate.

Acquisition and Processing of Maternal BP Signals

BP was measured on a beat-to-beat basis by an Ohmeda Finapres 2300 monitor. The analog pressure waveform was digitized at 250 Hz. Systolic BP (SBP) and diastolic BP (DBP) values were marked by peak/trough detection software and errors in marking were corrected interactively.

Acquisition and Processing of Fetal Signals

Fetal HR was measured by two methods. Instantaneous fetal HR was recorded via an ultrasound transducer (Advanced Medical Systems, IM76) and passed to the microcomputer acquisition system. In addition, using electrodes placed on the maternal abdomen and passed via a parallel port to a computer, fetal ECG monitor software (FEMO: Medco, Inc.) was used to dissect fetal ECG signals from the composite maternal/fetal waveform and to compute maternal and fetal RR intervals. The ECG waveform was digitized at 230

Hz. Only 3 subjects had useable ECG data for the duration of the entire protocol.

Maternal Anxiety

Anxiety was assessed using the state anxiety subscale of the State–Trait Personality Inventory (STPI) (Spielberger, 1979), a 10-item, self-report instrument. Developed by the same research team as the well-standardized State–Trait Anxiety Inventory (STAI), it has been found to be highly correlated with the state anxiety subscale of the STAI (Spielberger & Rickman, 1990). In addition, on both the STPI and STAI scales, state and trait anxiety scores are found to be highly associated (Spielberger, 1979; Spielberger & Rickman, 1990). State anxiety scores on the STPI can range from a minimum of 10 to a maximum of 40.

Statistical Analyses

Of the 20 subjects, 2 did not have useable fetal HR data from either the FEMO ECG or from ultrasound and 1 failed to complete the STPI. Of the remaining 17 subjects, 9 completed the arithmetic task and 8 completed the Stroop.

All analyses collapsed data across Stroop and arithmetic tasks. Paired *t* tests were used to analyze the effects of cognitive stressors when averaged across the entire stress period without regard to the influence of anxiety. Repeated measures ANOVAs were used to detect the effects of anxiety on response magnitude and time course of responses. However, because in our sample there was a trend for maternal responses to be greater during the Stroop task, all subsequent analyses include task type as a source of variance. In no case when there was a main effect of anxiety or an effect of anxiety on the time course of responses was there a significant interaction with task type. Following the repeated measures ANOVAs, *t* tests were used to characterize the significance of changes from baseline within groups at each time point. Alpha was set at .05 for these post hoc analyses.

RESULTS

Self-Reports of Stress

There were no significant differences between tasks on the mean self-reported level of stress during baseline or the mental challenge period. At baseline the subjects reported a level of 2.8 ($\pm$2.5) on the 10-point self-report stress scale. The mean self-reported level of stress during the psychological task was 7.2 ($\pm$2.6), a significant increase, $p < 0.0001$.

Maternal Cardiorespiratory and Fetal Heart Rate Activity at Baseline and During Cognitive Challenge

Mean baseline and mean changes in maternal HR, SBP, DBP, respiratory rate, and fetal HR (FHR) during the 5–min period of cognitive challenge are presented in Table 1. Reactivity to the task was computed as a within subject change score.

The average baseline systolic and diastolic blood pressures of these 17 mothers are above norms (Margulies et al., 1987; Reiss, Tizzano, & O'Shaughnessy, 1987) (116–120 systolic; 70 diastolic), yet they are comparable to data of nonpregnant subjects obtained during a baseline period preceding a psychophysiology laboratory testing session (Monk, Sloan, Fifer, Myers, & Bagiella, 1999; Sloan et al., 1997). The average baseline heart rate also was above the norm although only marginally higher than heart rates recorded from supine pregnant women in a previous study (Clark et al., 1991) and consistent with the finding of elevated pulse rate during pregnancy (Ashmead & Reed, 1997).

When averaged across all subjects without regard to anxiety scores, the cognitive stressors led to a sig-

Table 1. Maternal Cardiorespiratory and Fetal Heart Rate Values at Baseline and Reactivity to Psychological Challenge

	Baseline	Reactivity	Reactivity Range
Maternal HR (bpm)	97.1 ± 10.1	+1.6 ± 5.9	−10.2–10.2
Maternal SBP (mmHg)	133.0 ± 17.2	+7.0 ± 9.8**	−14.9–23.0
Maternal DBP (mmHg)	78.2 ± 12.8	+2.6 ± 6.1	−11.8–13.8
Maternal Respiratory Rate (cpm)	18.1 ± 3.5	+3.8 ± 4.1**	− 3.0–16.3
Fetal HR (bpm)	141.5 ± 10.8	+1.7 ± 4.8	−10.6–10.3

Note. Values are means ±*SD*. BP = blood pressure; SBP = systolic BP; DBP = diastolic BP.
**$p \leq .01$.

nificant increase in maternal SBP, $t^{15} = 2.90$, $p < .05$, and maternal respiratory rate, $t^{15} = 3.82$, $p < .01$, but changes in maternal HR, DBP, and fetal HR were not significant.

Maternal Anxiety Scores and Stress Ratings

The mean maternal state anxiety level was 18.5 ± 4.3 (range = 11 to 27), similar to the distribution found by Spielberger who reported mean state anxiety scores for women between 23–32 years old and 33 and older as 18.6 ± 6.8 and 18.2 ± 5.8, respectively (Spielberger, 1979). Anxiety scores were dichotomized at the mean creating a "higher than average" anxious group [ANX(+): $n = 10$, range = 19 to 27] and a "lower than average" anxious group [ANX(−): $n = 7$, range = 11 to 17]. In the ANX(+) group, 6 women received an arithmetic task and 4 completed the Stroop task; in the ANX(−) group, 3 women underwent the arithmetic task and 4 women completed the Stroop task.

On the 10-point, self-report stress scale, there were no significant group differences for the baseline or cognitive challenge periods. During baseline, ANX(+) subjects reported a level of 3.7 ± 3.0 and ANX(−) subjects reported a level of 1.8 ± 1.1, $F(1, 14) = 2.54$, $p = .13$. For ANX(+) subjects, the mean self-reported level of stress during cognitive challenge was 7.2 ± 3.0 and for ANX(−) subjects it was 7.1 ± 2.2, $F(1, 14) = .07$, $p = .85$.

Maternal and Fetal Cardiorespiratory Measures During Baseline by Anxiety Group

Mean baseline maternal HR, SBP, DBP, respiratory rate, and FHR for the two anxiety groups are presented in Table 2. There was no significant difference between maternal anxiety groups on any of the baseline measures, although the difference in maternal HR approached significance, $t^{15} = 1.69$, $p = .11$.

Table 2. Maternal Cardiorespiratory and Fetal Heart Rate Values at Baseline by Anxiety Group

	ANX (+)	ANX(−)
Maternal HR (bpm)	100.3 ± 11.9	92.4 ± 3.6
Maternal SBP (mmHg)	130.6 ± 20.5	137.0 ± 11.5
Maternal DBP (mmHg)	76.9 ± 15.2	80.0 ± 8.8
Maternal Respiratory Rate (cpm)	18.0 ± 2.4	18.0 ± 4.8
Fetal HR (bpm)	141.3 ± 12.4	141.8 ± 8.9

Note. Values are means ±*SD*. BP = blood pressure; SBP = systolic BP; DBP = diastolic BP.

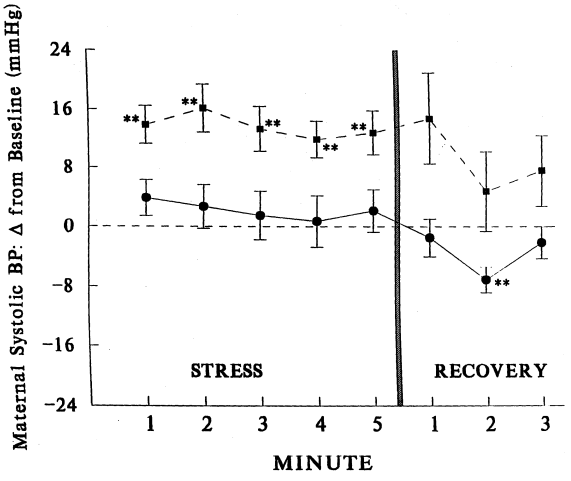

FIGURE 1 Mean (±*SE*) changes from baseline in maternal systolic blood pressure for the ANX(+) (filled circles, solid line) and the ANX(−) (filled boxes, dashed line) groups during each of the 5 min of stress and 3 min of recovery. Asterisks indicate a significant difference from baseline, *$p < .05$. **$p < .01$.

Maternal Cardiorespiratory Activity During the Stress and Recovery Periods by Anxiety Group

Figures 1–4 depict minute-by-minute change scores of maternal variables during the 5-min stressor and 3-

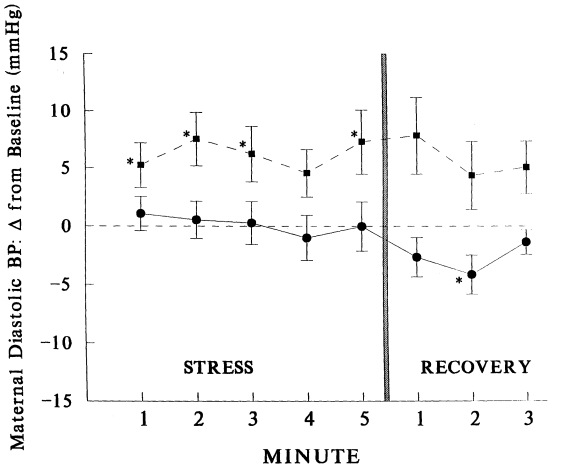

FIGURE 2 Mean (±*SE*) changes from baseline in maternal diastolic blood pressure for the ANX(+) (filled circles, solid line) and the ANX(−) (filled boxes, dashed line) groups during each of the 5 min of stress and 3 min of recovery. Asterisks indicate a significant difference from baseline, *$p < ,05$. **$p < .01$.

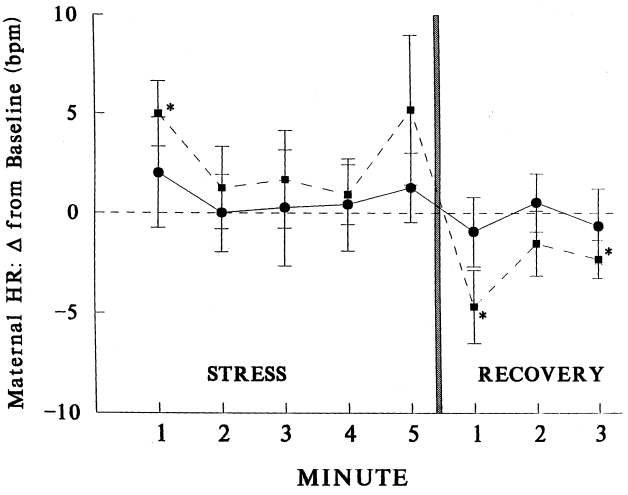

FIGURE 3 Mean (±*SE*) changes from baseline in maternal heart rate for the ANX(+) (filled circles, solid line) and the ANX(−) (filled boxes, dashed line) groups during each of the 5 min of stress and 3 min of recovery. Asterisks indicate a significant difference from baseline, *$p < .05$. **$p < .01$.

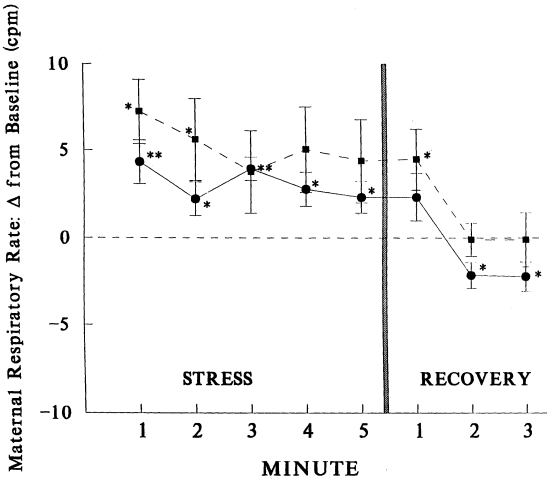

FIGURE 4 Mean (±*SE*) changes from baseline in maternal respiratory rate for the ANX(+) (filled circles, solid line) and the ANX(−) (filled boxes, dashed line) groups during each of the 5 min of stress and 3 min of recovery. Asterisks indicate a significant difference from baseline, *$p < .05$. **$p < .01$.

min recovery periods, with results of within group *t* tests of reactivity at each minute. Women's SBP responses to cognitive challenge differed significantly by anxiety group, $F(1, 13) = 9.10$, $p < .05$. ANX(−) subjects had significantly greater SBP increases compared to ANX(+) women. During each minute of the stressor and the 1st min of recovery, ANX(−) subjects' SBP values were significantly increased over their baselines whereas ANX(+) women showed no significant SBP changes during stress and only a significantly lower-than-baseline value during the 2nd min of recovery. A similar pattern was found for DBP. DBP changes were significantly greater for ANX(−) subjects than for ANX(+) subjects, $F(1, 13) = 6.42$, $p < .05$. ANX(−) women had significant DBP increases during every minute of the stressor period whereas ANX(+) subjects showed no significant changes in DBP. During recovery, the ANX(+) subjects showed a significant decrease in DBP during the 2nd min.

There were no significant group differences in maternal HR responses. Neither ANX(+) nor ANX(−) subjects showed significant HR changes during the 5-min cognitive challenge, although ANX(−) women had a significant HR increase during the 1st min of the cognitive challenge. During recovery, the ANX(−) subjects showed significant decreases in HR during the 1st and 3rd minutes.

Both groups showed significant respiratory rate increases to challenge but did not differ from each other across the 5-min task period. In the minute-by-minute within group analyses, ANX(−) subjects had significant respiratory rate increases during the first 2 min of the stressor period and the 1st min of recovery whereas ANX(+) subjects showed significant respiratory rate increases during all 5 min of the cognitive challenge and significantly lower than baseline values during the last 2 min of recovery.

Fetal Heart Rate During the Stressor and Recovery Periods by Maternal Anxiety Group

As shown in Figure 5, depicting the minute-by-minute values of FHR during the stressor and recovery periods, FHR changes during mothers' exposure to a mental stressor differed significantly by anxiety group,[1] $F(1, 13) = 5.88$, $p < .05$. Fetuses of ANX(+) mothers had significantly greater FHR increases during the stressor period compared to those in the ANX(−) group. The pattern of FHR changes over the 8 min of maternal challenge and recovery also differed significantly by maternal anxiety group, $F(1, 13) = 11.40$, $p < .01$. During each minute of the stressor, ANX(+) FHR values were significantly greater than baseline whereas none of the FHR values of ANX(−) fetuses was significantly different from baseline. By the 3rd min of recovery, both groups were near baseline lev-

[1]For 2 subjects, there was 1 min of missing FHR data for the recovery periods. For these two data points, FHR was interpolated based on values of previous and succeeding heart rates.

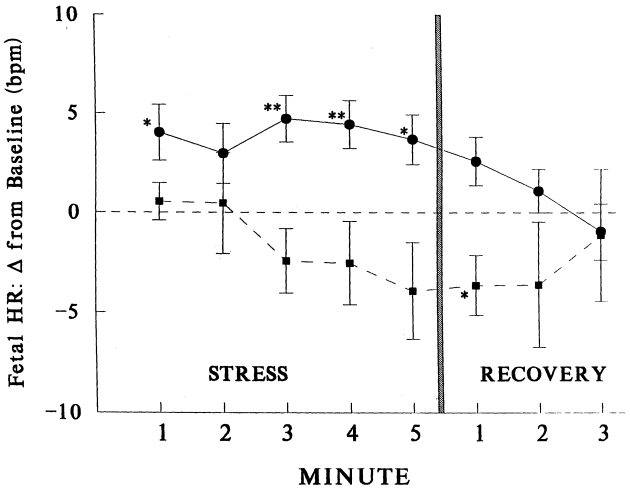

FIGURE 5 Mean (±*SE*) changes from baseline in fetal heart rate for the ANX(+) (filled circles, solid line) and the ANX(−) (filled boxes, dashed line) groups during each of the 5 min of stress and 3 min of recovery. Asterisks indicate a significant difference from baseline, $^{*}p < .05$, $^{**}p < .01$.

els. In the ANX(+) group, there was a gradual increase in FHR and then a slow return toward baseline levels whereas in the ANX(−) group there was a gradual, nonsignificant decrease in FHR and then a slow return to baseline levels.

DISCUSSION

In this study, we concurrently monitored maternal and fetal physiology while mothers' responded to a cognitive challenge to examine the relationship between pregnant women's acute stress responses and FHR and to determine the effect of differences in maternal state anxiety levels on these responses.

As predicted, there was a significant increase across all subjects in maternal SBP and respiratory rate during mental challenge. However, there was no significant change in maternal DBP or HR. This latter result of nonsignificant HR and DBP reactivity to mental challenge is in contrast to findings with male and nonpregnant female subjects (Sloan et al., 1997; Sloan et al., 1996) as well as one report of women in the three different trimesters of pregnancy (McCubbin et al., 1996). However, it is consistent with data showing diminished DBP responses to mental challenge during the 2nd trimester and with the hypothesis that elevations in female reproductive hormones depress sympathetic nervous system reactivity (Matthews & Rodin, 1992). It is important to note that in none of these prior studies were the potential effects of subject's anxiety on physiological reactivity analyzed.

We found women's psychophysiologic reactivity was significantly related to their status on the STPI anxiety inventory. However, contrary to our predictions and some previous reports (Johnson & Hanson, 1977; Whitehead, Blackwell, Desilva, & Robinson, 1977), it was the "lower than average" anxiety group [ANX(−)] that exhibited significant increases in systolic and diastolic BP during mental challenge. The BP increases in the ANX(−) group were similar in magnitude to increases of nonpregnant subjects undergoing cognitive challenge (Matthews & Rodin, 1992; Sloan et al., 1997). There were no group differences in maternal HR or respiratory rate changes; neither group showed significant HR changes during challenge and both groups showed significant increases in respiratory rate. These findings are similar to recent results based on a comparable experiments of acute reactivity in nonpregnant subjects which suggest that anxiety is associated with physiological inflexibility rather than hyperarousal (Hoehn-Saric, McLeod, & Hipsely 1995; Young, Nesse, Weder, & Julius, 1998). They point to the potential role of anxiety in modulating psychophysiologic responses and suggest that the buffered reactivity found in pregnancy may result from altered hemodynamics and/or from increased anxiety during pregnancy and the concomitant changes in physiology.

Although FHR across all fetuses did not change significantly during acute maternal stress, stratification of the data by maternal anxiety status allowed the significant association between acute maternal stress and FHR to emerge. Fetuses of mothers in the ANX(+) group showed significant HR increases during the stressor period whereas fetuses of the ANX(−) group did not. Thus, in the ANX(+) group of subjects, in which women showed buffered physiologic responses to mental challenge except for respiratory rate, the fetuses showed significant increases in HR. In contrast, in the ANX(−) group, in which mothers showed significant reactivity in systolic and diastolic BP as well as respiratory rate to the cognitive challenge, the fetuses of these mothers did not exhibit a significant HR change. These data indicate that FHR reactivity is relatively independent of the maternal pressor response: FHR may increase in the absence of maternal BP and HR responses and may not change in the presence of significant maternal responses. These findings suggest that increases in maternal BP during stress, which can be associated with maternal vasoconstriction and, consequently, decreases in uteroplacental blood flow, are not necessarily required for FHR increase. However, they do not rule out the possibility that an increase in maternal BP could trigger FHR reactivity in the context of other stress-related changes in maternal physiology.

Five alternative hypotheses have been considered to account for these findings: (a) The fetus senses and responds to changes in maternal respiratory rate. As state anxiety is generally found to be highly correlated with trait anxiety (the personality characteristic of a tendency to feel anxious), over time the development of fetuses of women who experience chronic anxiety is altered such that they have different thresholds for HR reactivity. Thus, fetuses of higher-than-average anxious women are already distinct from other fetuses; compared to fetuses of lower-than-average anxious women they show hyperreactive responsiveness to the same maternal input, i.e., increased breathing rate. (b) Fetuses in the two anxiety groups are responding to different physiological changes in their intrauterine environments. For example, perhaps fetuses in the higher-than-average anxiety group respond to their mothers' consistently elevated respiratory rate by increasing their HR whereas fetuses in the lower-than-average anxiety group—also exposed to maternal elevations in respiratory rate—respond to mothers' BP increases by attenuating their HR reactivity. (c) Unmeasured variables such as maternal uterine activity, maternal cortisol, or depth of breathing may mediate the association between fetal heart rate reactivity and maternal anxiety. (d) Women who have above-average anxiety also may have greater psychophysiologic arousal anticipating the start of the laboratory session and, in turn, have reduced responses during cognitive challenge itself. The fetal HR increase in the ANX(+) group then could be a delayed response to mothers' anticipatory reactivity during baseline that is triggered by mothers' change in respiratory rate. (e) ANX(+) women's adrenergic receptors may have been downregulated due to repeated stimulation (Young, 1998). Thus, although these women exhibit diminished BP reactivity to stress, they may have increased catecholamine secretion that affect the fetus either directly or indirectly.

Our findings are consistent with the general hypothesis of long-term sequelae of in utero exposure to maternal emotions. The magnitude and frequency of acute alterations in maternal breathing rate associated with shifts in emotion may alter the fetus' threshold for stimulus reactivity, with implications for future physiologic–behavioral reactivity patterns (Fifer & Moon, 1995; Sandman, Wadhwa, Hetrick, Porto, & Peeke, 1997). Maternal HPA activation associated with maternal stress and anxiety may have a direct impact on the fetus through the positive placental–adrenal feedback loop established during pregnancy (Wadhwa et al., 1996). The release of maternal cortisol stimulates placental release of corticotrophin-releasing-hormone (CRH), which in turn stimulates the maternal pituitary–adrenal axis to secrete cortisol, leading to further placental CRH secretion. Although this positive placental–adrenal feedback loop is established in all pregnancies, recent research suggests that maternal stress is positively associated with maternal neuroendocrine parameters. Maternal stress may expose the fetus to increased levels of adrenal hormones with possible consequences for fetal central nervous system development and, in particular, glucocorticoid brain receptor development (Meany et al., 1996; Vallee et al., 1997; Wadhwa et al., 1996).

Our findings suggest that fetal heart rate is influenced by maternal stress and anxiety. They are consistent with other emerging research indicating that women's chronic and acute emotions during pregnancy are associated with alternations in fetal heart rate and sleep patterns (DiPietro et al., 1996b; DiPietro et al., 1996a; Groome et al., 1995). Specifically, it is interesting to speculate about the possible convergence of data from DiPietro's work on fetuses of chronically stressed mothers and our findings on fetuses of more highly anxious women undergoing a laboratory stressor. Would fetuses of chronically stressed mothers, who have reduced baseline fetal heart rate variability as DiPietro has found, have greater heart rate reactivity during a maternal mental stressor? Would fetuses of ANX(+) mothers show reduced heart rate variability during baseline? Such findings would further indicate that fetuses of "stressed" and anxious pregnant women evidence alterations in autonomic balance suggestive of diminished cardiac vagal control and/or greater sympathetic modulation.

This study has several limitations. First, the sample size was small. Second, we measured subjects' level of anxiety by only one self-report instrument and used the mean on the anxiety scale to dichotomize subjects into high- and low-anxiety groups. Furthermore, we did not control for fetal state at the beginning of the testing sessions. As Groome et al. (1995) have found that fetuses of anxious women spend more time in quiet sleep, it is possible that our data showing an association between levels of maternal anxiety and fetal heart rate reactivity indicate a state-dependent difference in fetal HR reactivity. However, the lack of differences in baseline fetal heart rate is not consistent with fetal state differences. Finally, as previously noted, the baseline maternal systolic and diastolic blood pressures of these women were above norms. The elevated baseline readings may not be "true baselines," but rather measures reflecting an anticipatory response to the laboratory session. Alternatively, despite use of support under the right lower back, maternal postural position over time could have elevated readings. However, as blood pressure during baseline was unrelated to blood pressure change during the mental challenge, there is no indication of a "ceiling"

effect, $r = .18$. In fact, ANX(+) women who showed diminished reactivity during the stressor had lower BP during baseline (see Table 2). Future studies based on a larger sample, multiple methods of assessing maternal anxiety, and classification of fetal state based on an assessment of fetal HRV and movement will address these weaknesses.

In summary, our data suggest that fetuses of mothers with high maternal anxiety show significant heart rate increases during maternal cognitive stress compared to fetuses of mothers with comparatively low maternal anxiety who show nonsignificant HR decreases under the same conditions, despite the opposite patterns of BP reactivity in the mothers. Although we do not yet know if the alteration in fetal cardiac reactivity related to maternal anxiety is "situational" or indicative of long-lasting changes, the findings support the growing evidence that maternal emotions affect fetal neurobehavioral development.

NOTES

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