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Maternal depression during pregnancy is associated with increased birth weight in term infants

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Abstract

Previous research of maternal depression during pregnancy suggests an association with low birth weight in newborns. Review of these studies reveals predominant comorbidity with premature birth. This current study examines antenatal depression and birth weight in term, medically low-risk pregnancies. Maternal physiological and demographic measures were collected as well. In total, 227 pregnant women were recruited to participate in four experimental protocols at Columbia University Medical Center. Results indicate that depressed pregnant women who carry to term had significantly higher heart rates, lower heart rate variability, and gave birth to heavier babies than those of pregnant women who were not depressed. Low income participants had significantly higher levels of depression, as well as significantly higher heart rates and lower heart rate variability, than those in higher income groups. In full-term infants, maternal prenatal depression appears to promote higher birth weight, with elevated maternal heart rate as a likely mediating mechanism.

KEYWORDS

birth weight, heart rate, heart rate variability, maternal depression, neonatal outcomes, newborn, pregnancy, prenatal depression

1 | INTRODUCTION

For over two decades researchers have explored the effects of maternal antenatal depression on infant outcomes, with one of the pervasive findings that depression during the prenatal period results in low birth weight (Field, Diego, & Hernandez-Reif, 2006; Marcus, 2009; Orr & Miller, 1995; Schetter & Tanner, 2012; Steer, Scholl, Hedgier, & Fischer, 1992). Review of these studies reveals that the focus is often on high-risk pregnancies, in which maternal depression is comorbid with other maternal and perinatal risk factors, including preterm birth. Schetter and Tanner (2012) estimate that two-thirds of low birth weight infants are born preterm. In a review of 35 studies conducted over the last two decades, higher levels of depression during pregnancy were found to contribute independently to obstetric complications, negative pregnancy symptoms, preterm labor, and pain relief issues during labor (Alder, Fink, Blitzer, Holi, & Hollygrove, 2007). In this review, three out of the five studies examining effects of maternal depression during pregnancy on birth weight found an association with low birth weight. However, birth weight was not examined independently of gestational age in those studies. Others have found that the association between maternal depression and low birth weight is attenuated when adjusted for gestational age (Chang et al., 2014). A recent meta-analysis of antenatal depression and birth outcomes finds depressed pregnant women are at increased risk for both preterm birth and delivering low birth weight newborns (Grote et al., 2010). Grigoriadis et al. (2013), in a meta-analysis of perinatal

outcomes of maternal depression during pregnancy, find a significant association between antenatal depression and prematurity, but not low birth weight.

Arias and Tomich (1982) point out that prematurity is traditionally defined as birth weight lower than 2,500 g, which has led to the conflation of premature rupture of membranes (PROM), or "preterm," with small for gestational age (SGA), in the literature. In a review of 895 studies between 1970 and 1984, Kramer (1987) found no link between maternal psychological factors and "intrauterine growth retardation (IUGR)," but did find possible effects on preterm birth. Grote et al. (2010) reported similar findings regarding antenatal depression, IUGR, and prematurity in their more recent review, but report a relationship with low birth weight as well.

The distinction between low birth weight and prematurity is important because the etiological mechanisms need not be identical. Field and her colleagues suggest that the association between maternal mood and early physiology is mediated by cortisol and norepinephrine in the maternal blood (Field et al., 2002, 2004; Field et al., 2006), and the association between those two factors is purported to be different in the case of low birth weight versus prematurity (Field et al., 2010; Kramer et al., 2009; Schetter & Tanner, 2012). However, there appear to be limited investigations of the impact of maternal depression on birth weight in term neonates in medically low-risk pregnancies, where differences in preterm birth and low birth weight are carefully defined, both methodologically and statistically.

Marcus, Flynn, Blow, and Barry (2003) report approximately 20% of pregnant women meet criteria of depression on the Center for Epidemiological Studies Depression Scale (CES-D). Depression and autonomic nervous system (ANS) regulation have been found to be related in non-pregnant women (Wang et al., 2013). Depressed non-pregnant women are at risk for significantly higher heart rates and lower heart rate variability, a pattern that can persist despite antidepressant medication (Jandackova, Britton, Malik, & Steptoe, 2016). Tonhajzerova, Visnovcova, Mestanikova, Jurko, & Mestanik (2016) point to irregularities in the neurocardiac reflex system associated with depression as the mechanism underlying this pattern. Only one study has explored cardiac measures in pregnant women as related to antenatal depression, suggesting a similar pattern of higher heart rate and lower heart rate variability (Shea et al., 2008). Everett, Mahendru, McEnierry, Wilkinson, and Lees (2013) reported that higher maternal heart rates during the second semester of pregnancy are positively associated with higher birth weight. Taken together, these findings indicate possible connections between maternal mood, ANS function during pregnancy, and infant birth weight.

A number of other factors have been related to higher birth weight. For example, obese pregnant women are more likely to give birth to heavier babies (Carolina et al., 2014; Sebire et al., 2001). Obesity has been found to be associated with significantly lower heart rate variability in adult women (Karason, Molgaard, Wikstrand, & Sjostrom, 1999; Rossi et al., 2015; Sant Anna Junior et al., 2015). Dragan and Akhtar-Danesh (2007) report that higher body mass index (BMI) may also be associated with more severe forms of depression. Molyneaux et al. (2016) found that obesity was associated with increased risk of depression in high SES pregnant women only, but that antenatal depression is more common in low SES women regardless of BMI. Depression is significantly associated with low income across ethnicities (Costello, Farmer, Angold, Burns, & Erkanli, 1997; Cutrona, Russell, Brown, & Clark, 2005; Johnston, Johnson, McLeod, & Johnston, 2004), and low income women are at highest risk for depression (Belle & Doucet, 2003). Little information is available comparing the autonomic profiles of low income pregnant women that are experiencing depression, or how this might relate to pre-pregnancy BMI and birth weight in term newborns.

Our approach to addressing the comorbidity of preterm birth and low birth weight, while exploring the associations between birth weight and maternal factors, is to focus on full-term neonates recruited from low risk maternal-fetal dyads. This investigation addresses four questions. What is the autonomic profile of depressed pregnant women in the context of a medically low-risk pregnancy? Does this profile change in the context of maternal pre-pregnancy BMI? What is the impact of economic disadvantage on these measures? And finally, what is the association between these maternal measures and infant birth weight when the pregnancy is term? We hypothesize that depression is related to birth weight in fullterm infants, and that maternal BMI, SES, and autonomic function mediate that association.

2 | METHODS

2.1 | Sample

The participants were 227 pregnant women that were recruited from the obstetrics clinic and enrolled in in four separate studies conducted at Columbia University Medical Center. All studies were reviewed and approved by the New York State Psychiatric Institute (NYSPI) Institutional Review Board. Inclusion criteria were: no gestational diabetes, hypertension, or other related medical conditions, and no cigarette, alcohol, illicit or prescription drug use during pregnancy. Only women with singleton pregnancies were included. Four women did not complete the depression scale and so were dropped from the analyses. Mean age of pregnant women was 26 years (±6 SD). Testing took place at 36 weeks gestation ($M = 36.2$ weeks ± 0.5 SD). Gestational age was determined using medical charts. Frequency distributions for demographic variables are given in Table 1. The majority of participants were Latina, had a family income of less than $25,000, and were receiving Women, Infant, Children (WIC) Food and Nutrition Service. About half of participants were overweight or obese. BMI was calculated from maternal self-reports of height and pre-pregnancy weight. For 54% of the women this was their first pregnancy; the remaining participants had on average one previous birth; parity ranged from zero to five previous births.

2.2 | Study 1 ($N = 59$)

Maternal cardiac data (ECG) were collected during a baseline period that was part of a 30 min fetal study examining fetal movement and heart rate response to sound (Ecklund-Flores et al., 2012). Prior to initiation of the

TABLE 1 Demographic characteristics of participants (%)

Gender of fetus	Male	52
	Female	48
Ethnicity	Caucasian	16
	African-American	11
	Latina	68
	Asian	4
	Other	1
Education	Less than High School	13
	High School Diploma	35
	College	23
	Bachelor Degree	12
	Graduate Degree	17
Income (annual family)	Less than $15,000	34
	$16,000–$25,000	21
	$26,000–$50,000	17
	$51,000–$99,000	18
	$100,000 or more	10

sound protocol, the pregnant women were seated in a comfortable reclining chair, in a slightly left-oriented supine position. They were tested in a darkened room and wore ear plugs and head phones. Four standard ECG leads were placed on the mothers' abdomen and these were attached to the Monica™ AN24 Abdominal Electrocardiogram monitor, which is a noninvasive method of collecting maternal and fetal cardiac activity simultaneously. When these recordings were complete, women were escorted to a private area to complete a demographic survey, SES survey (Stewart, Dean, Gregorich, Brawarsky, & Haas, 2007), Perceived Stress Survey (PSS) (Cohen, Kamark, & Mermelstein 1983) and the Center for Epidemiologic Studies Depression Scale (CESD) (Radloff, 1977). The CESD can be used as a continuous or a dichotomized variable. As suggested by Radloff, when dichotomized a standard cut-off of 16 is used to indicate not depressed/depressed.

2.3 | Studies 2, 3, and 4 (*N* = 168)

Baseline maternal ECG was collected from a standard adult heart rate monitor prior to three separate protocols examining the association between maternal heart rate, blood pressure, respiration rate, and fetal heart rate in response to a psychological challenge (e.g., Stroop Task) (Monk et al., 2010; Monk et al., 2004; Monk et al., 2000). Maternal data were collected while resting quietly in a semi-recumbent position during a 5 min baseline period prior to the beginning of the cognitive task. Before testing began, these women were interviewed by a licensed mental health professional using the Scheduled Clinical Interview for the DSM-IV (SCID) for history and psychiatric assessment, and also completed the PSS (Cohen et al., 1983) and CESD (Radloff, 1977).

2.4 | Data analysis

In Study 1, the raw fetal electrocardiogram (ECG) files were exported to a text file, and interpolated and processed through custom software (Matlab, Gmark). The maternal ECG file was exported for automated r-wave and R-R interval detection and conversion to instantaneous heart rate (IHR). ECG is used as a routine measure of cardiovascular integrity, and measures the number of R-wave events (heartbeats) in the QRS complex (the ECG waveform corresponding to the contraction of the ventricles); instantaneous heart rate is the number of R-wave events in 1 min (Barbieri, Matten, Alabi, & Brown, 2004; Moody, 2016). Measures of heart rate variability focused on the calculation of beat-to-beat variability—the root mean square of successive differences in R-to-R intervals (RMSSD), a time domain index of vagal modulation of heart rate (Berntson et al., 1997).

In Studies 2, 3, and 4, maternal heart rate data were collected via analog electrocardiogram (ECG) using a standard HR monitor (Hewlett Packard 78292A). Analog ECG signals were digitized at 500 Hz (National Instruments 16XE50). R waves were marked and beat-to-beat variability was calculated as described above.

To account for differences between studies in methodology, instrumentation, and length of study, maternal heart rate and beat-to-beat heart rate variability data were adjusted by study. This conservative approach to account for possible study effects was accomplished by using heart rate and heart rate variability residuals after regression in which study was entered as the predictor variable. Neonatal birth weight was adjusted for gestational age at birth and sex using the same technique; birth weight residuals after regression were used, in which gestational age and sex were entered as the predictor variables. Subsequently, adjusted heart rate, adjusted heart rate variability and adjusted birth weight values were entered into all analyses.

MANOVA was used to compare maternal HR and HRV in depressed (*N* = 76) and non-depressed groups (*N* = 128). Subsequent two-way MANOVAs were used to make these comparisons across pre-pregnancy BMI categories in depressed and non-depressed groups. Partial correlations were computed between CESD and PSS and the maternal autonomic measures to quantify the degree to which each predicts independently of the other. Chi-square Tests of Independence were used to compare frequency of depression across socioeconomic categories, and additional two-way MANOVAs were used to explore maternal autonomic measures across income categories in depressed and non-depressed mothers. Simple correlation and *t*-tests were used to compare birth weight and maternal depression. Multiple linear regression was used to predict birth weight by pre-pregnancy BMI and depression. To further understand the associations between depression, maternal heart rate and heart rate variability and birth weight, the procedures recommended by Baron and Kenny (1986) and Preacher, Rucker, and Hayes (2007) for testing mediational effects were utilized. In addition, SPSS AMOS was used for Structural Equation Modeling and path analysis estimation to test the hypothesized associations.

3 | RESULTS

3.1 | Depression and maternal autonomic measures

Thirty-four percent of pregnant mothers across all studies were scored as depressed on the CES-D (≥16). This is approximately twice the

reported incidence rate (18%) in pregnant women (Marcus, 2009), and higher than the reported estimation that 25% of poor mothers meet the criteria for major depression (Belle & Doucet, 2003).

A one-way MANOVA was performed to determine the effect of depression category on resting maternal heart rate and heart rate variability. A significant effect was found [*Lambda* (2,201)=0.934, $p = .001$]. Subsequent univariate ANOVAs indicated that heart rate was significantly higher in depressed pregnant women [$F(1,202) = 13.145$, $p < .001$] and heart rate variability was significantly lower [$F(1,202) = 8.547$, $p = .004$], see Figure 1.

3.2 | Depression, stress, and maternal autonomic measures

There was a significant correlation between depression (CESD) and perceived stress (PSS) in our studies [$r(223) = 0.647$, $p < .001$]. There was also a significant difference in stress by depression category; Not Depressed $M = 20.21$ (±6.14) Depressed $M = 28.60$ (6.60) [$t(204) = -9.1124$, $p < .001$]. The correlation between CESD and maternal heart rate and heart rate variability was significant; CESD x MHR [$r(204) = .222$, $p = .001$] and CESD x RMSSD [$r(204) = -.17$, $p = .015$]. The correlation between PSS and maternal heart rate was significant [$r(109) = 0.235$, $p = .001$] but the correlation with maternal heart rate variability was not [$r(190) = -.088$, $p = 0.226$]. When partial correlations were completed for the relationships between stress and the maternal autonomic measures controlling for depression, neither association was significant (PSS x MHR [$r(184) = 0.126$, $p = .09$]; PSS x RMSSD [$r(184) = .036$, $p = 0.625$]). When partial correlations were completed for depression and the maternal autonomic measures controlling for perceived stress, both relationships were maintained; (CESD x MHR [$r(184) = 0.210$, $p = .017$]; CESD x RMSSD [$r(184) = -.133$, $p = .044$]). These analyses demonstrate that even though there is a strong correlation between perceived stress and depression, depression independently predicts maternal heart rate and heart rate variability while perceived stress does not.

3.3 | Maternal BMI, depression, and maternal autonomic measures

BMI was calculated by measuring participant's height and reported pre-pregnancy weight [(Weight in pounds/ Height in inches^2) x 703]. Data for computing maternal pre-pregnancy BMI were available for 77% of the participants ($N = 176$). Of those women, 4% were underweight, 50% were within the normal range, 28% were overweight, and 18% were obese. These prevalence rates are within the national average (Centers for Disease Control and Prevention, 2014).

An Independent Samples *t*-test found no difference in maternal pre-pregnancy BMI between Not Depressed ($M = 25.05$, ±4.67 SD) and Depressed ($M = 25.54$, ±5.73 SD) participants. Pearson correlations found no significant correlation between depression and maternal pre-pregnancy BMI and no significant correlations were found between pre-pregnancy BMI and maternal heart rate measures (see Table 2).

Maternal heart rate measures were examined in the context of depression and pre-pregnancy BMI categories. A two-way MANOVA revealed a significant effect for depression [*Lambda* (2,148) = 0.93, $p = .006$], but not for BMI, nor for the interaction. Depressed women had significantly higher heart rate [$F(1,156) = 16.97$, $p < .001$], and lower heart rate variability [$F(1,156) = 7.39$, $p = .007$]. This pattern persisted across pre-pregnancy BMI categories, see Figure 2.

3.4 | Income, education, depression, and maternal autonomic measures

Chi-square Tests of Independence were calculated comparing the frequency of depression across levels of education and income. A significant interaction was found for both education [$\chi^2(4) = 10.16$, $p = 0.03$] and income [$\chi^2(4) = 13.35$, $p = 0.01$]. Women from higher education and income groups had lower incidences of depression. Univariate ANOVAs using continuous depression scores confirmed this association: women from low education groups [$F(4,201) = 2.89$,

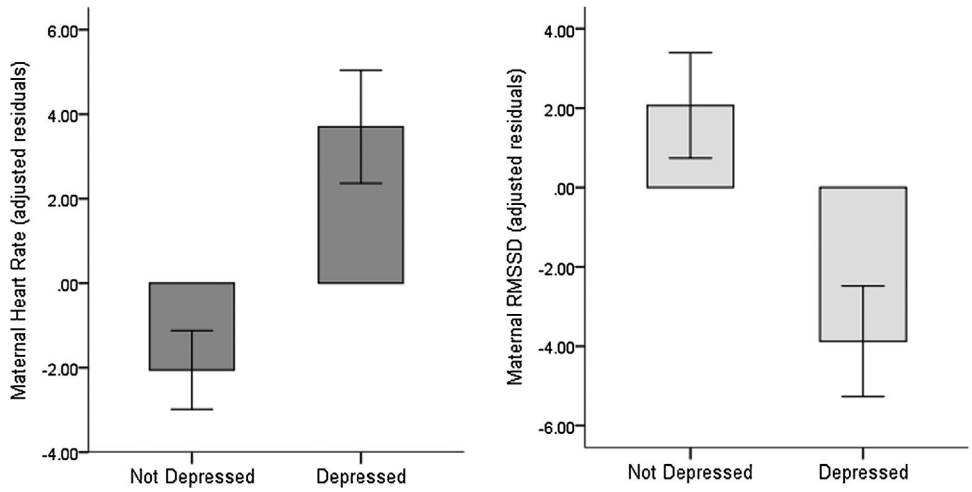

FIGURE 1 Depression and resting maternal heart rate ($p < .001$) and heart rate variability ($p = .004$). Not Depressed $N = 128$, Depressed $N = 76$. Maternal heart rate and beat-to-beat variability (RMSSD) are adjusted residuals after regression in which study was entered as the predictor variable. Error bars represent ±1 SEM

TABLE 2 Descriptive statistics for all study variables

			Correlations					
	Mean	SD	Age	BMI	Income	CESD	RMSSD	MHR
Age (years)	26.45	6.02						
BMI	25.32	4.99	−.01					
Income ($US)	20,160	12,330	.44[a]	−.03				
CESD	14.77	9.28	−.11	.11	−.20[a]			
RMSSD	22.92	14.59	−.02	−.06	.23[a]	−.17[b]		
MHR (bpm)	90.09	11.39	−.23[a]	.11	−.27[a]	.22[a]	−.58[a]	
Birth Weight (g)	3410.42	396.59	−.19[a]	.11	−.07	.16[b]	−.13*	.20[a]

BMI, body mass index calculated from pre-pregnancy weight; CESD, Center for Epidemiological Studies Depression Scale (Radloff, 1977); RMSSD, the root mean square of successive differences in R-to-R intervals.
[a]Correlation significant at .01 level.
[b]Correlation significant at .05 level.
*$p = .058$.

$p = 0.02$] and income groups [F(4,184) = 3.68, $p = .007$] had significantly higher depression scores.

A two-way MANOVA was calculated to determine the effects of income level and education level on resting maternal heart rate and heart rate variability. A significant effect was found for income [*Lambda*(12, 387) = 0.851, $p = .02$] but not for education. Heart rate was significantly increased in low income groups [F(4,173) = 3.694, $p = .007$] and heart rate variability was significantly decreased [F(4,173) = 2.95, $p = .022$], see Figure 3.

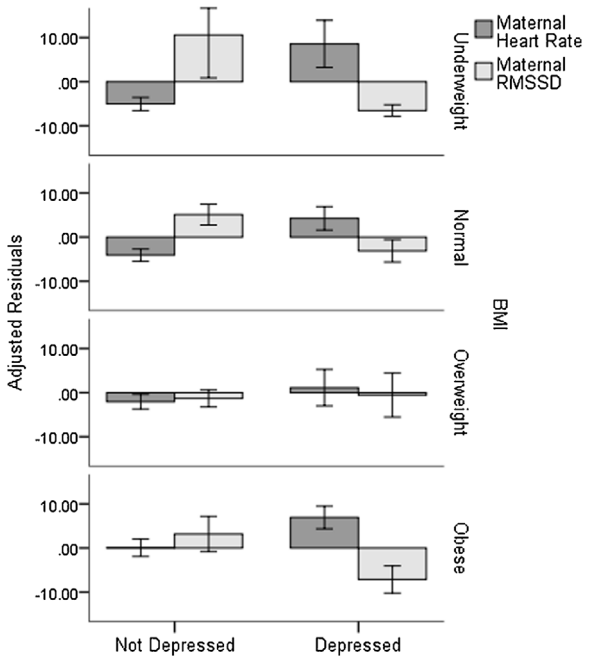

FIGURE 2 Maternal heart rate, heart rate variability, and depression in the context of maternal prepregnancy BMI. Heart rate variability (RMSSD) is the root mean square of successive differences in R-to-R intervals, that is, beat-to-beat variability, a time domain index of vagal modulation of heart rate (Berntson, et al., 1997). BMI categories based on cutoffs established by the Center for Disease Control and Prevention (2014)—Underweight $N = 7$ (below 18.5) Normal weight $N = 87$ (18.5–24.9) Over weight $N = 46$ (25–29.9) Obese N=30 (30 and above). Significant main effect for depression ($p = .006$) but not BMI. Error bars represent−± 1 SEM

3.5 | Depression and birth weight

Mean birth weight for across all studies was 3,410 g (± 397), with a range of 2,560–4,825 g. The Pearson correlation coefficient between continuous maternal depression scores and birth weight revealed a weak but significant positive relationship (r(220) = +0.16, $p = .015$). Higher levels of maternal depression are related to higher birth weight in their full-term newborns. When dichotomized into depression groups (Depressed vs. Not Depressed), a marginal effect on birth weight was found. Babies from mothers in the Depressed category had higher birth weights (3,477 g ± 439) than those in the Not Depressed group (3,373 g ± 371). Birth weights were marginally, but not significantly, different [t(220) = 1.89, $p = 0.06$].

Information about weight gained during pregnancy was available for Study 1 ($N = 59$). Mean weight gained during pregnancy for this group was 29.46 lbs (±14.37). Pregnant women in the Depressed category ($M = 29.96$, ±17.47) did not gain significantly more weight during pregnancy than those pregnant women in the Not Depressed group ($M = 29.49$, ±13.04) for this subset. No association between maternal weight gain during pregnancy and birth weight was found.

3.6 | Maternal heart rate measures and birth weight

To examine the association between maternal autonomic measures and birth weight, maternal heart rate and heart rate variability were divided into tertiles, and birth weight was compared across these three categories. A one-way ANOVA revealed significant differences in birth weight based on maternal heart rate [F(2, 201) = 4.438, $p = .014$]. Women with higher heart rates gave birth to significantly heavier babies. A similar analysis revealed significant differences in birth weight based on maternal heart rate variability [F(2, 201) = 8.28, $p < 0.001$]. Women with lower heart rate variability gave birth to heavier babies, see Figure 4.

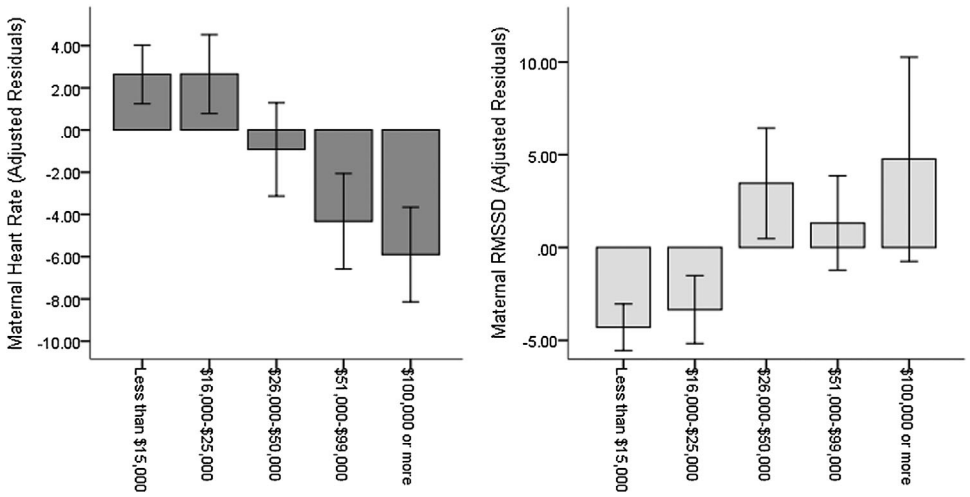

FIGURE 3 Income and resting maternal heart rate ($p = .007$) and heart rate variability ($p = .02$). As previously stated, maternal heart rate and beat-to-beat variability (RMSSD) are adjusted residuals after regression in which study was entered as the predictor variable. Sample size for each income category is given in Table 1. Error bars represent ± 1 SEM

3.7 | Maternal BMI, depression, and birth weight

A multiple linear regression was calculated to predict birth weight based on depression and pre-pregnancy BMI. A significant regression equation was found [$F(2, 166) = 3.43$, $p = 0.035$] with an R^2 of 0.04. Depression was a significant predictor of birth weight ($p = 0.02$) but pre-pregnancy BMI was not ($p = 0.25$).

3.8 | Income, depression, and birth weight

Although not significantly different, depressed pregnant women with a family income of less than $25,000 gave birth to the heaviest babies (3,534 g ± 474), followed by depressed women with family income of more than $25,000 (3,408 g ± 374), and women that were not depressed in either low income (3,394 g ± 360), or higher income (3,384 g ± 392) categories.

3.9 | Mediation

Descriptive statistics for the study variables are presented in Table 2 as well as the correlations among these variables. Depression was positively correlated with maternal heart rate and birth weight, and negatively correlated with maternal beat-to-beat heart rate variability. Maternal heart rate variability was negatively associated with maternal heart rate, a relationship which is expected from the literature (Billman, 2013; Hart, 2013). Maternal heart rate and birth weight were positively correlated. Income was negatively associated with maternal heart rate, and positively associated with heart rate variability. Income was not significantly associated with birth weight. Maternal age was positively correlated with income, and negatively correlated with heart rate and birth weight. There were no significant correlations between maternal pre-pregnancy BMI and any other variables.

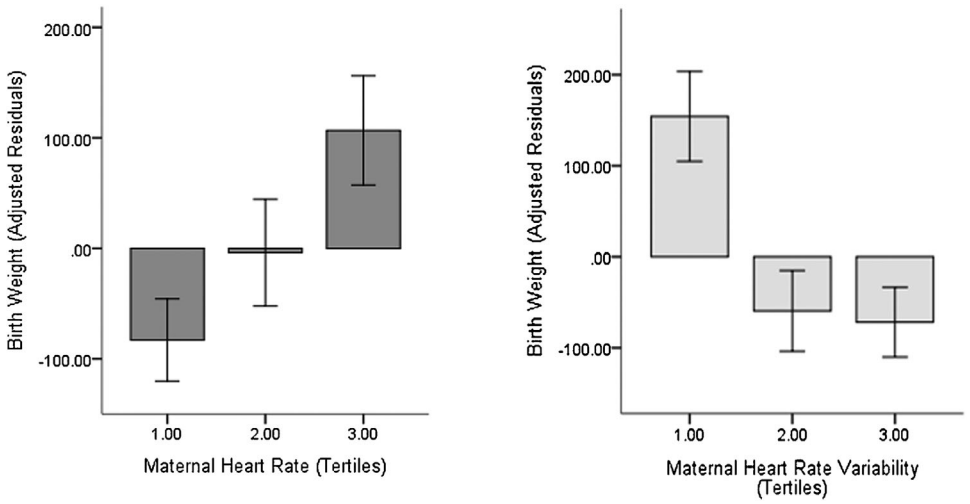

FIGURE 4 Birth weight by maternal heart rate ($p = .013$) and heart rate variability ($p < .001$). $N = 69$ for each tertile. Birth weight is adjusted residuals after regression in which gestational age and sex were entered as the predictor variables. Error bars represent ± 1 SEM

Mediational effects (Baron & Kenny, 1986; Preacher et al., 2007) were analyzed and structural equation modeling and path analyses were estimated to test the hypothesized associations. In this model depression is a significant predictor of birth weight, and this effect is fully mediated by maternal heart rate. Maternal heart rate variability partially mediates the effect of depression on maternal heart rate. See Figure 5 for the estimated standardized path coefficients of the proposed model. Thirty-five percent of the variance in depression's effect on maternal heart rate can be explained by the mediating influences of maternal heart rate variability in this model, which, in turn, accounts for about 5% of the variance in depression's effect on birth weight.

4 | DISCUSSION

Our results show that autonomic regulation is altered by depression in pregnant women near term, and suggest that birth weight is affected as a function of this association. In non-pregnant women depression has a significant impact on heart rate variability, and as heart rate variability decreases, heart rate increases (Wang et al., 2013). Beat-to-beat heart rate variability is a measure of parasympathetic control and indicates cardiovascular "lability" (Porges, 2007), so lowered heart rate variability compromises cardiovascular responsiveness. A "close, bidirectional relationship between depression and cardiovascular disease is well established" and decreased beat-to-beat rate variability has been identified as one of several possible "pathophysiological mechanisms" (Nemeroff & Goldschmidt-Clermont, 2012, p.526). Animal model studies corroborate the association between depression and adverse cardiovascular outcomes, with symptoms including increased heart rate, reduced heart rate variability, and increased arrhythmias (Grippo et al., 2012).

Our results indicate that depression during pregnancy is positively correlated with birth weight. This appears to contradict literature that suggests a negative correlation between depression and birth weight. The separation of birth weight from gestational age in this study has illuminated the importance of carefully defining these variables in future investigations of the impact of maternal depression during pregnancy.

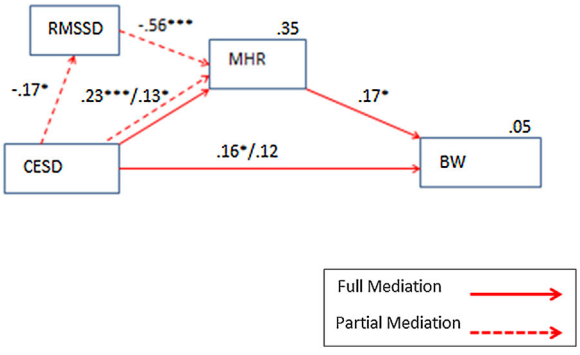

FIGURE 5 Estimated standardized path coefficients for the effect of depression on birth weight. Thirty-five percent of variance in heart rate is accounted for by the mediating effects of heart rate variability; 5% of the variability in birth weight is accounted for by the mediating effects of heart rate. *$p < .05$, **$p < .01$, ***$p < .001$

The relationships between stress, anxiety, and depression during pregnancy and the subsequent impact of these factors on maternal autonomic regulators and birth outcomes continue to be studied from different perspectives. Tonhajzerova et al. (2016) found that stress modifies cardiovagal control in the context of depression. The PREDO study (Pesonen et al., 2016) found that increased depression and anxiety increase the risk of preterm birth, while Kramer et al. (2009) found only anxiety associated with preterm birth. In our analyses we were able to effectively distinguish between perceived stress and depression and their impact on autonomic regulation, revealing depression to be an independent predictor of maternal heart rate and heart rate variability in pregnant women while controlling for stress. Moreover, depression was also significantly associated with birth weight while stress was not.

In our study, depression was negatively associated with income; those participants living at the poverty level have the highest levels of depression. Heart rate and heart rate variability were also significantly affected by the moderating influences of income. Significantly lower heart rate variability and elevated heart rate were associated with economic disadvantage and depression.

Costello et al. (1997) reported an association between poverty and depression, and Johnston et al. (2004) found significantly higher rates of depression in low income groups. Low social support, stressful life events, and financial strain have both been found to increase the risk of depression (Kessler et al., 2012). As reported in the National Institute of Health Strategic Plan (Volume 1, 2002–2006) a "destructive synergy" exists between socioeconomic status, health practices, psychological stress, and environmental stress—which combine to affect biological processes and ultimately health outcomes. In this cohort, pregnant depressed women in low income brackets were observed to be more likely to have high heart rates and low heart rate variability. Depression therefore provides one mechanism by which economic disadvantage leads to physiological compromise in pregnant women.

In the present study, pre-pregnancy BMI was not correlated with depression, and mean pre-pregnancy BMI was not different between depressed and not depressed groups. In addition, depression remained a significant predictor of heart rate and beat-to-beat variability regardless of maternal pre-pregnancy BMI category. Although elevated heart rate has been associated with obesity (Blumberg & Alexander, 1992), our study did not support this finding when depression and pre-pregnancy BMI were entered into the analysis together. However, Carson, Powrie, and Rosene-Montella, (2002) compared the incidence of sinus tachycardia (defined as ≥100 beats/min) in pregnant obese and non-obese women, and found that when lying in a left lateral position there was no significant difference between these groups. In our studies, data were collected when women were in a left lateral recumbent position, which strengthens our conclusion that depression is the factor driving the elevated heart rates we find, not obesity.

We hypothesize that elevated heart rate in depressed pregnant women is a potential mechanism for increased birth weight in those fetuses carried to term. Higher heart rates in depressed women may indicate increased cardiac output and therefore better perfusion of the uterus/placenta, resulting in increased supply of oxygen and nutrients to the fetus. Our model points to decreased heart rate variability, due to economic disadvantage and depression, as a potential factor underlying increased heart rate in these women.

4.1 | Limitations

Sixty-eight percent of the participants were Latina, making valid ethnicity comparisons questionable. Latina and African-American women had significantly higher pre-pregnancy BMIs in this cohort than Caucasian or other ethnic groups. Further, pre-pregnancy BMI data were missing for 23% of participants. There was also a time discrepancy between data collection points; BMI data were calculated from pre-pregnancy weight while all other variables were collected during the 36th week of pregnancy. Ethnicity and BMI are variables that require further exploration.

Baseline maternal heart rates were found to be significantly higher in studies 2, 3, and 4 than in study 1, thereby requiring that heart rate data be adjusted by study group. Methodological differences in data collection are the likely cause of this. For example, depression and stress surveys were administered before testing in those studies in which resting maternal heart rate was higher; in study one these surveys were administered after testing. The use of adjusted residuals for maternal heart rate measures was an effective method of controlling for these differences.

While birth weight was highest in the babies of depressed poor women, there was not a significant association between income and birth weight in this cohort, probably due to sample size. Further investigation of the interrelationship between depression, income, and birth weight is warranted.

5 | CONCLUSION

In term infants, maternal depression appears to promote higher birth weight, with elevated maternal heart rate as a likely mechanism, indicating that this important marker of child health and growth is shaped in utero, and is related to maternal mood.

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