


Influence of maternal exercise on fetal heart response during labor and delivery

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Abstract

Objectives: The purpose of this study was to determine if prenatal exercise alters the maternal and fetal heart responses during labor and delivery. We hypothesized that fetuses of exercising mothers would exhibit a lower baseline heart rate (HR), increased HR variability (HRV), and no differences in fetal heart accelerations and decelerations.

Design: This study employed a cross-sectional design.

Methods: The Modifiable Physical Activity Questionnaire was used for group classification. Exercising women were those participating in 30 minutes of moderate-to-vigorous exercise at least 3×/week throughout the entire pregnancy. Women achieving a lower dose of exercise were classified as non-exercisers. Cardiotocography recordings during the first hour of labor and delivery assessed fetal baseline HR, HRV, accelerations, decelerations, and contractions. ANCOVA analyses were performed to assess group differences in these outcomes and were adjusted for maternal body mass index.

Results: Thirty-one women were included in the analyses. No group mean differences were found for maternal and fetal characteristics, except for maternal age (EX: mean (SD) 28.5 (±4.6y) vs NON-EX: 24.1 (±1.2y)). After controlling for body mass index, no statistical differences in maternal HR response ($\beta = 3.9$, SE = 5.0, 95%CI -6.4-14.2) or fetal HR response ($\beta = 3.9$, SE = 2.5, 95%CI -1.2-9.11), accelerations and decelerations ($\beta = -0.03$, SE = 0.4, 95%CI -0.9-0.8; $\beta = -0.10$, SE = 0.4, 95%CI -0.8-0.9, respectively), or HRV ($\beta = 0.6$, SE = 1.7, 95%CI -2.8-4.0) were observed.

Conclusions: Based on the findings of this study, we found no evidence that maternal exercise during pregnancy was associated with maternal or fetal HR response during labor and delivery. These data suggest maternal exercise may not elicit positive or negative effects on maternal and fetal cardiovascular responses to the physiological stress of labor and delivery.

KEYWORDS

aerobic, cardiovascular, fetal, pregnancy, training

Institution: Vidant Medical Center Labor and Delivery, East Carolina University, Fitness, Instruction, Testing and Training (FITT) building, East Carolina Heart Institute (ECHI) gym in Greenville NC

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1 | INTRODUCTION

Fetal heart rate (HR) is modulated via the autonomic system and, thus, serves as an excellent marker of normal fetal development and maturation during the prenatal and perinatal period.¹ Specifically, the assessments of fetal HR, HR variability (HRV), and HR patterns (ie, accelerations and decelerations) are indicators of proper fetal oxygenation, distress, and general well-being, especially during labor and delivery.² Evidence suggests that lower fetal HR and increased HRV are indicative of optimal fetal heart health.² Conversely, higher fetal HR and lower HRV are markers of distress and may result in poor fetal outcomes.³⁻⁵

While fetal HR and HRV are affected by several maternal and fetal factors (eg, gestational age and body mass index),⁶ growing evidence suggests regular maternal exercise may have a profound influence on fetal heart function and development.⁷⁻⁹ Specifically, evidence suggests that regular maternal exercise during pregnancy is associated with lower fetal HR and increased HRV, indicating decreased fetal distress and less abnormal fetal HR patterns.⁷⁻¹⁰ Alterations to placental development and function (eg, increased villous vascular volume, and increased placental growth and function) and fetal responses (eg, increased HR and lean mass) during exercise are identified as potential mechanisms that underlie the relationship between maternal exercise and fetal heart health.^{11,12} Similarly, maternal exercise during pregnancy exhibits improvements in maternal heart function. Studies demonstrated that physically active women have lower resting HR and increased HRV¹³ during pregnancy.

Labor and delivery pose significant physical stressors for both the mother and fetus.¹⁴ As such, the positive effects of maternal exercise on maternal and fetal heart function may alleviate the physical stress during this time. Decrements in the imposed physical stress may reduce maternal fatigue during both stages of labor and delivery, thereby facilitating a faster recovery in the immediate postpartum period and reducing the risk of caesarean delivery. To our knowledge, no studies have previously evaluated the association between maternal exercise during pregnancy on maternal and fetal heart response during labor and delivery. Thus, the primary aim of this study was to determine if exercise during pregnancy alters maternal and fetal heart response during labor and delivery.

2 | MATERIALS AND METHODS

This study employed a cross-sectional study and was designed to investigate the association between self-reported maternal exercise during pregnancy and fetal HR and HRV, maternal HR, and pregnancy outcomes, during labor and delivery. The East Carolina University Institutional Review Board approved this study.

All women were recruited from the Labor and Delivery unit at local hospital in North Carolina. Women between the ages of 18 and 40 years, with a body mass index (BMI) between 18.5 and 34.9 kg/m² and more than 37 weeks pregnant, with a singleton pregnancy, and who delivered a single, viable infant within the past 6 weeks, were recruited for this study. Women were not eligible for this study if they were smokers, had a history of alcohol or drug use, or used

medications, in the prenatal and perinatal period, known to affect maternal and fetal HR and HRV.¹⁵⁻¹⁷ Additionally, women needing induction into labor were excluded from the study. In total, 37 women were recruited for this study. All women consented to participate in this study either prior to their delivery or within a few hours in the immediate postpartum period. Six women were excluded, due to BMI criteria ($n = 3$), medications ($n = 1$), or delivery complications ($n = 2$). As a result, 31 women were eligible for this study. To reduce selection bias, eligible women were randomly selected using a random numbers table. Informed consent was obtained prior to study enrollment. Following consent, all women completed an activity questionnaire, and a medical record release to access labor and delivery records, which included the HR parameters of interest that are routinely collected during labor and delivery.

Maternal physical activity and demographic information were collected via the Modified Physical Activity Questionnaire (MPAQ), which has been shown to be reliable in general populations, including pregnancy, and validated against doubly labeled water tests, accelerometry, and measures of energy expenditure.¹⁸⁻²¹ The MPAQ was provided to participants in the immediate postpartum period following labor and delivery, typically within a few hours or the following day. The MPAQ inquiries about patient demographics as well as a recall of physical activity frequency and intensity 3 months prior to pregnancy and during each month of pregnancy (9 months), covering a total of 12 months. For the purpose of this study, only physical activity (PA) in the prenatal period served as the primary exposure variable.

Because participation in PA at moderate-to-vigorous intensity is demonstrated to elicit important health benefits and is recommended by the American College of Obstetricians and Gynecologists and American College of Sports Medicine for non-pregnant and pregnancy populations,^{22,23} only participation in moderate and vigorous physical activities was included in the analysis. In order to determine physical activity intensity, we used the compendium of physical activity to determine metabolic equivalent (MET) levels for all activities reported.^{24,25} Moderate-to-vigorous intensity was defined as aerobic activities with MET values >3.0 METs.²⁶ To determine the volume of moderate-to-vigorous physical activity (MVPA), each activity (in METs) was multiplied by its frequency (# of days per week) and duration (in minutes). Thus, the volume of MVPA was expressed as METs·min⁻¹·week⁻¹.

Following this, women were assigned to two groups (exercise or non-exercise). Women were considered "exercisers" if they performed at least 30 minutes of MVPA, 3 times per week throughout pregnancy, as recommended by American College of Obstetricians and Gynecologists and American College of Sports Medicine.^{7,8,13,22,27,28} Women that reported not consistently participating in this dose of PA were considered "non-exercisers." Of the 30 participants, 17 were classified as "exercisers" and 13 as "non-exercisers."

Fetal heart parameters (ie, HR, HRV, # of contractions, # of accelerations and decelerations) were gathered from a cardiotocogram. Specifically, a continuous abdominal cardiotocography using the GE Corometrics 170 series monitor was used to record fetal and maternal heart rhythms and contractions. The first hour of recorded fetal heart monitoring (from the time of admission through labor and delivery) was used for analysis. The first hour was divided into six 10-minute

intervals, and three of these six intervals were selected using a random numbers table. Thus, a total of 30 minutes was analyzed for each participant. Two Maternal-Fetal Medicine physicians (EN and JL), who were blinded to group classification (ie, "exercise" vs "non-exercise"), independently read all tracings. Each physician recorded baseline fetal HR, fetal HRV, number of accelerations, number of decelerations, and number of contractions for each 10-minute segment. HRV was determined by measuring the peak-to-trough amplitude (bpm) of fluctuation from baseline HR, excluding accelerations or decelerations within the 10-minute interval. HR tracings were excluded if any narcotics, epidural anesthesia, corticosteroids, or magnesium sulfate were given within the first hour. Other maternal (ie, body weight and height) and fetal (ie, birthweight, length and head circumference, APGAR scores) health parameters were gathered from medical records.

Prior to analyses, the appropriate assumptions for each analysis were assessed and satisfied. Student *t*-tests and Wilcoxon rank sum tests were used to compare maternal and fetal measures between groups (exercise, non-exercise) for continuous outcomes. Chi-squared tests were performed to analyze the differences in delivery method and infant sex between groups. Separate ANCOVA analyses were performed to assess the association between maternal exercise and maternal HR, number of maternal contractions, fetal baseline HR, and HR variability. Because maternal BMI is demonstrated in the literature to impact all the aforementioned outcomes and maternal participation in exercise prior to and during pregnancy,^{29,30} maternal BMI was included as a covariate and expressed as a continuous variable. Despite the significant differences found for maternal age between the exercise and non-exercise groups, it was not included as a covariate in the analyses. The scientific literature does not indicate dramatic physiological differences between the ages of the women in this study that might impact maternal exercise or any of the maternal and fetal outcomes.³¹

3 | RESULTS

All 31 women had healthy pregnancies and delivered term, healthy infants (20 females, 11 males). No statistically significant differences in maternal or fetal demographics were present between the exercise and non-exercise group with the exception of maternal age. Women in the exercise group were, on average, older (mean 28.5, SD 4.6 vs 24.1 ± 1.2 yr.; $t_{(27)} = -2.53$, $p = 0.01$) compared with the women in the non-exercise group (Table 1).

The common physical activities in which these women participated throughout pregnancy are displayed in Table 2. Walking was the most prevalent activity. Depending on the activity, the duration tended to increase (most for the "exercisers") from the first to the second trimester, followed by a decline. Perceived intensity of each activity appeared to increase; this is likely due to the increased weight gain documented during pregnancy. Few women participated in more vigorous activities (eg, running); however, participation in these activities declined rapidly in participant frequency, intensity, and duration after the first trimester.

Table 3 depicts the maternal and fetal heart responses during labor and delivery between the women in the exercise and non-

TABLE 1 Maternal and infant characteristics between exercising and non-exercising women

Maternal:	Exercise <i>n</i> = 16	Non-exercise <i>n</i> = 15	<i>P</i> Value
Age (years)	28.5 (4.6)	24.1 (1.2)	0.01
BMI (kg·m ²)	25.6 (7.1)	27.2 (5.5)	0.54
Gestation (weeks)	39.3 (1.4)	38.7 (2.1)	0.31
Gravida ^a	2.0 (1-10)	2.0 (1-5)	0.48
Parity ^a	1.0 (0-5)	1.0 (0-3)	0.59
Delivery method (%)			0.60
Vaginal	81.3	66.7	-----
Caesarean section	12.5	26.7	-----
Operative vaginal	6.3	6.7	-----
Infant:			
Birth weight (grams)	3376.1 (467.7)	3271.3 (466.6)	0.54
Birth length (cm)	49.3 (0.7)	49.2 (2.2)	0.94
Head circumference (cm)	33.4 (1.9)	33.4 (0.5)	0.98
Sex			
% female	56.3	73.3	0.48
Apgar 1 min ^a	8.0 (5.0-9.0)	9.0 (7.0-9.0)	0.10
Apgar 5 min ^a	9.0 (6.0-9.0)	9.0 (9.0-9.0)	0.22

^aMedians and ranges are reported, and Wilcoxon Rank Sum Test was used to determine differences between groups. Gravida refers to the maternal history of the number of pregnancies, whereas parity refers to the number of live children.

exercise groups. No statistically significant differences were found between the groups.

The adjusted linear regression coefficients for the association between maternal exercise and maternal and fetal heart responses during labor and delivery are presented in Table 4. For the maternal HR response, there was no statistically significant association between maternal exercise and maternal HR ($\beta = 3.9$, SE = 5.0, 95%CI -6.4-14.2). Similarly, maternal exercise was not found to be associated with the number of contractions in the mother during labor and delivery ($\beta = -0.4$, SE = 0.5, 95%CI -1.4-0.6). For the fetal HR responses, there were no associations found between maternal exercise and baseline fetal HR ($\beta = 3.9$, SE = 2.5, 95%CI -1.2-9.1) and number of accelerations and decelerations ($\beta = -0.03$, SE 0.4, 95%CI -0.9-0.8; $\beta = 0.1$, SE 0.4, 95%CI -0.8-0.9), respectively. Similarly, no associations were found between maternal exercise and fetal HR variability ($\beta = 0.6$, SE 1.7, 95%CI -2.8-4.0).

4 | DISCUSSION

The primary aim of this study was to assess the association between maternal exercise during pregnancy on maternal and fetal HR responses during labor and delivery. We hypothesized that during labor and delivery, there would be lower baseline fetal HR, lower maternal HR, and increased fetal HRV, with no differences in fetal heart accelerations and decelerations in the exercise group relative to the non-exercise group. Contrary to our hypotheses, the results of this study suggest there are no associations between maternal exercise and maternal and fetal HR response during labor and delivery. As

TABLE 2 Duration and intensities of common maternal physical activities, by trimester and group

Activities/Intensity (%)	Group Assignment					
	"Exercisers"			"Non-exercisers"		
	Trimester			Trimester		
Walking	1 st (n = 15)	2 nd (n = 17)	3 rd (n = 17)	1 st (n = 10)	2 nd (n = 8)	3 rd (n = 6)
Duration (min/wk)	119.6	123.1	118.9	83.9	72.5	50.6
Intensity (%)						
Low	13.3	11.5	9.9	20.0	21.4	47.3
Moderate	66.7	71.1	77.8	80.0	82.7	52.7
High	20.0	17.3	18.0	0.0	0.0	0.0
Yoga	1 st (n = 7)	2 nd (n = 4)	3 rd (n = 2)	1 st (n = 1)	2 nd (n = 2)	3 rd (n = 2)
Duration (min/wk)	74.9	99.0	75.0	52.5	146.3	146.3
Intensity (%)						
Low	42.1	19.0	0.0	0.0	50.0	50.0
Moderate	43.0	62.2	50.0	100.0	50.0	50.0
High	14.4	24.4	50.0	0.0	0.0	0.0
Strength training	1 st (n = 6)	2 nd (n = 8)	3 rd (n = 7)	1 st (n = 0)	2 nd (n = 0)	3 rd (n = 0)
Duration (min/wk)	100.0	100.3	71.5	-----	-----	-----
Intensity (%)				-----	-----	-----
Low	16.7	12.5	14.4	-----	-----	-----
Moderate	83.0	87.5	85.5	-----	-----	-----
High	0.0	0.0	0.0	-----	-----	-----
Gardening	1 st (n = 6)	2 nd (n = 5)	3 rd (n = 3)	1 st (n = 3)	2 nd (n = 2)	3 rd (n = 1)
Duration (min/wk)	106.4	41.5	139.2	19.2	4.6	7.5
Intensity (%)						
Low	38.9	60.0	30.6	100.00	100.0	100.0
Moderate	61.0	40.0	69.4	0.0	0.0	0.0
High	0.0	0.0	0.0	0.0	0.0	0.0
Swimming	1 st (n = 4)	2 nd (n = 4)	3 rd (n = 2)	1 st (n = 0)	2 nd (n = 0)	3 rd (n = 0)
Duration (min/wk)	102.2	118.1	63.3	-----	-----	-----
Intensity (%)				-----	-----	-----
Low	25.0	6.6	44.4	-----	-----	-----
Moderate	50.0	64.4	55.6	-----	-----	-----
High	25.0	28.9	0.0	-----	-----	-----
Average exercise	1 st	2 nd	3 rd	1 st	2 nd	3 rd
METs per week ^a	10 519.8 (2430.7)	10 424.5 (1761.9)	8269.4 (5909.1)	2400.9 (858.6)	1667.5 (510.5)	895.3 (353.0)

^aMeans and standard deviations are reported.

TABLE 3 Maternal and fetal HR responses to labor and delivery between exercising and non-exercising women

	Exercise (n = 16)	Control (n = 15)	P Value
Maternal:			
Maternal HR (bpm)	90.3 (13.5)	87.1 (14.5)	0.59
Contractions	2.1 (1.2)	2.4 (1.6)	0.50
Fetal:			
Baseline FHR (bpm)	139.9 (6.7)	136.2 (7.2)	0.14
Accelerations	1.4 (1.2)	1.5 (1.0)	0.94
Decelerations	0.5 (1.1)	0.5 (1.2)	0.88
HR variability (bpm)	17.0 (5.2)	16.0 (4.4)	0.58

Note: The units for maternal contractions and fetal accelerations and decelerations are (number per 10 min). Student *t*-tests were performed to determine between-group differences.

such, we conclude that maternal participation in exercise is neither helpful nor harmful to the response of the maternal and fetal cardiovascular systems during parturition.

Although it is known that maternal exercise during pregnancy blunts the natural increasing HR with advancing gestation¹³ and that maternal HR increases during labor,³² the response of maternal HR in active women during labor and delivery has not been thoroughly investigated. Our findings suggest that there are no differences in maternal HR response during the physiological stress of labor, regardless of the level of prenatal exercise.

There are a few possible explanations for these findings. One explanation for the lack of difference in maternal HR response between groups is due to the stage of labor in which maternal HR was measured. Research indicates that maternal HR increases during

TABLE 4 Regression coefficients from ANCOVA analysis for the associations between maternal exercise and maternal and fetal heart outcomes

Outcomes	Regression Coefficient (β)	Standard Error	95% CI
Maternal			
Heart rate (bpm)	3.9	5.0	[-6.4, 14.2]
Contractions	-0.4	0.5	[-1.4, 0.6]
Fetal			
Baseline HR (bpm)	3.9	2.5	[-1.2, 9.1]
Accelerations	-0.03	0.4	[-0.9, 0.8]
Decelerations	0.1	0.4	[-0.8, 0.9]
HRV (bpm)	0.6	1.7	[-2.8, 4.0]

Non-exercise group served as the referent group. All models controlled for maternal BMI. Note: The units for maternal contractions and fetal accelerations and decelerations are in number per 10 min.

Abbreviation: HRV, heart rate variability.

contractions, and more contractions occur in stage 2 relative to stage 1.^{33,34} Although the exact stage of labor in which women were was not known in this study, no differences in number of contractions during labor and delivery were present between groups, suggesting the women were in similar stages during HR recordings.

Another explanation for these null findings is that the position of the women during the recording was not controlled for in the analyses. Research demonstrates that ambulation and upright positions are associated with shorter labor duration.³⁵ Shorter labor duration likely reduces the physical intensity exerted by the mother and lowers her level of overall fatigue during parturition, effectively reducing her HR response to the physiological stress of labor and delivery. Lastly, maternal HR response may not adequately represent the cardiovascular response to the stress of labor and delivery. Exposure to a physiological stress elicits a response from the cardiovascular system to include HR, stroke volume, and cardiac output.³⁶ It is possible that maternal cardiac output, stroke volume, and ventricular contractility increased significantly, with less of change in HR. In addition, the response of these cardiovascular parameters potentially differs between the exercise and non-exercise groups, given the established cardiovascular adaptations with exercise.³⁷ Cardiac output, stroke volume, and ventricular contractility, however, were not assessed in this study. As such, future investigations examining the cardiovascular response to labor and delivery should include these parameters.

The observation of similar fetal HR response during labor and delivery between exercise and non-exercising mothers was unexpected. Previous research demonstrated lower fetal HR and increased HRV at rest when exposed to regular maternal exercise during pregnancy.⁷ The fetal HR response was dose dependent, similar to the adaptation found in exercise-trained adults (eg, lower resting HR).^{7,9} As such, we anticipated a lower fetal HR and increased HRV during labor and delivery, suggesting a fetal HR training effect consequent to maternal exercise. However, this hypothesis was not supported. A potential explanation for the similar fetal HR response between exercise and non-exercise groups is the time period in which the fetal heart responses were recorded. To standardize the measurement time period, fetal HR measurements were recorded during the first hour of

labor and delivery, indicating these women were likely in the early stages of the labor. Consequently, these women likely experienced a significantly lower physiological stressor, reflected by a maternal HR corresponding to light exertion and normal fetal HR (see Table 3). Therefore, the exposure to a less vigorous physiological stressor in the first hour of labor and delivery may have precluded our ability to detect any significant differences in maternal and fetal heart responses that are attributable to maternal prenatal PA.

In support of this speculation, Sönchen et al (2011) found significantly greater maternal HRs during the latter stages of pregnancy, with HRs reaching 170 bpm for over 50% of the subjects.³² This HR reflects vigorous exertion that is typical during the active stage of labor and delivery. Importantly, significant differences in maternal HRs during this stage of labor were found between active and inactive women, with the former exhibiting a lower maternal HR. Fetal HR was not assessed in that study; however, because maternal and fetal HR patterns are similar during labor and delivery, we speculate that fetuses of active women would have also exhibited a lower HR due to the maternal exposure of a less vigorous physiological stressor.

Interestingly, research has shown that the post-exercise recovery HR in adults is faster in exercise-trained adults relative to non-exercise controls.³⁸ Although fetal recovery HR was not measured in this study, future research with the focus of fetal HR and maternal exercise, should consider assessing the difference in neonatal HR recovery immediately following labor and delivery between fetuses exposed to maternal exercise during pregnancy. It is possible that fetal HR during labor and delivery may not differ between exercise and non-exercising mothers, as indicated by the findings of this study; however, the fetal HR among exercising mothers may recover more quickly compared with fetuses born to non-exercising mothers. In support of this, previous studies demonstrated a significantly faster fetal HR recovery following an acute bout of maternal exercise in fetuses exposed to chronic exercising mothers.³⁹

This study has strengths and limitations that warrant attention. Importantly, this is the first study to assess maternal and fetal HR responses to the physiological stress of labor and delivery between exercising and non-exercising mothers. Despite our inability to find differences between maternal and fetal HR responses, as hypothesized, these findings provide preliminary information about the relationship between maternal exercise and fetal heart responses during labor and delivery. Another strength of this study is the rigorous measurements of maternal and fetal HR. These measurement methods provide objective and accurate assessments of cardiovascular parameters. Some limitations of this study include the sample size, study design, and measurement of maternal exercise. The small sample size used in this study likely resulted in insufficient power, precluding our ability to detect differences between the exercise and non-exercise group. Next, our employment of a cross-sectional study design limited our ability to assess maternal exercise during pregnancy. This is critical because evidence indicates that exercise in pregnancy declines considerably, especially in the third trimester. In addition, the use of self-reported maternal exercise is a significant limitation. Considering that maternal exercise is a positive health behavior,²² it is possible that social desirability affected the responses of the women. Consequently, misclassification may have been present, leading to inaccurate data;

we, however, utilized the same questionnaire and cut-offs that previously found differences in resting maternal HR during pregnancy in exercisers vs controls.^{13,20} Lastly, the stage of labor and the position (ie, ambulatory, supine), factors known to affect HR, were not taken into account.¹⁴

5 | CONCLUSION

In conclusion, this study suggests that maternal HR response during labor and delivery does not differ between exercising and non-exercising mothers during pregnancy. Further, this study suggests that exercise participation during pregnancy is neither helpful nor harmful in relation to fetal HR response during parturition and supports the most recent committee opinion (2015) by The American College of Obstetrics and Gynecology.²² Additional studies are needed to further explore the influence of maternal exercise on maternal and fetal HR. Specifically, maternal HR recovery after delivery and the utility of a cardiorespiratory fitness test a few weeks prior to the onset of labor would be informative. Because cardiorespiratory fitness is a strong indicator of habitual exercise,⁴⁰ its evaluation may provide a more accurate assessment of exercise behavior and, thus, a more precise estimation of the favorable or unfavorable fetal HR responses during labor and delivery. Future investigations should also consider employing longitudinal or randomized controlled exercise interventions, rigorous assessments of maternal exercise and fitness, and larger samples of pregnant women.

ACKNOWLEDGEMENTS

We would like to thank the participants who gave of their time to participate in the study.

CONFLICT OF INTEREST

The authors have declared that there is no conflict of interest.

DECLARATIONS

We have no competing interests to disclose. This study is supported by funds from East Carolina University. All authors have contributed to conceptualization and development of this manuscript.

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REFERENCES

1. Porges SW, Furman SA. The early development of the autonomic nervous system provides a neural platform for social behavior: a polyvagal perspective. *Infant Child Dev.* 2011;20(1):106-118. <https://doi.org/10.1002/icd.688>
2. Sampson MB, Mudaliar NA, Lele AS. Fetal heart rate variability. *Postgrad Med.* 1980;67(5):207-215. <https://doi.org/10.1080/00325481.1980.11715459>
3. DiPietro JA, Hodgson DM, Costigan KA, Hilton SC, Johnson TR. Fetal neurobehavioral development. *Child Dev.* 1996;67(5):2553-2567.
4. Allister L, Lester BM, Carr S, Liu J. The effects of maternal depression on fetal heart rate response to vibroacoustic stimulation. *Dev Neuropsychol.* 2001;20(3):639-651. https://doi.org/10.1207/S15326942DN2003_6
5. Halmesmaki E, Ylikorkala O. The effect of maternal ethanol intoxication on fetal cardiotocography: a report of four cases. *Br J Obstet Gynaecol.* 1986;93(3):203-205.
6. Voegtline KM, Costigan KA, Henderson JL, DiPietro JA. Fetal heart rate and motor development in overweight and obese pregnant women. *Int J Gynaecol Obstet.* 2016;133(1):103-107. <https://doi.org/10.1016/j.ijgo.2015.08.006>
7. May LE, Glaros A, Yeh H-W, Clapp JF 3rd, Gustafson KM. Aerobic exercise during pregnancy influences fetal cardiac autonomic control of heart rate and heart rate variability. *Early Hum Dev.* 2010;86(4):213-217. <https://doi.org/10.1016/j.earlhumdev.2010.03.002>
8. May LE, Suminski RR, Berry A, Langaker MD, Gustafson KM. Maternal physical activity mode and fetal heart outcome. *Early Hum Dev.* 2014;90(7):365-369. <https://doi.org/10.1016/j.earlhumdev.2014.04.009>
9. May LE, Suminski RR, Langaker MD, Yeh HW, Gustafson KM. Regular maternal exercise dose and fetal heart outcome. *Med Sci Sports Exerc.* 2012;44(7):1252-1258. <https://doi.org/10.1249/MSS.0b013e318247b324>
10. Dietz P, Watson ED, Sattler MC, Ruf W, Titze S, van Poppel M. The influence of physical activity during pregnancy on maternal, fetal or infant heart rate variability: a systematic review. *BMC Pregnancy Childbirth.* 2016;16(1):326. <https://doi.org/10.1186/s12884-016-1121-7>
11. Bergmann A, Zygmunt M, Clapp JF 3rd. Running throughout pregnancy: effect on placental villous vascular volume and cell proliferation. *Placenta.* 2004;25(8-9):694-698. <https://doi.org/10.1016/j.placenta.2004.02.005>
12. Clapp JF III, Kim H, Burciu B, Lopez B. Beginning regular exercise in early pregnancy: effect on fetoplacental growth. *Am J Obstet Gynecol.* 2000;183(6):1484-1488.
13. May LE, Knowlton J, Hanson J, et al. Effects of exercise during pregnancy on maternal heart rate and heart rate variability. *Phys Med Rehabil.* 2016;8(7):611-617. <https://doi.org/10.1016/j.pmrj.2015.11.006>
14. Soma-Pillay P, Catherine N-P, Tolppanen H, Mebazaa A, Tolppanen H, Mebazaa A. Physiological changes in pregnancy. *Cardiovasc J Afr.* 2016;27(2):89-94. <https://doi.org/10.5830/CVJA-2016-021>
15. Herbert CM, Boehm FH. Prolonged end-stage fetal heart rate deceleration: a reanalysis. *Obstet Gynecol.* 1981;57(5):589-593.
16. Boehm FH, Woodruff LFJ, Growdon JHJ. The effect of lumbar epidural anesthesia on fetal heart rate baseline variability. *Anesth Anal.* 1975;54(6):779-782.
17. American College of Obstetricians and Gynecologists. ACOG Practice Bulletin No. 106: intrapartum fetal heart rate monitoring: nomenclature, interpretation, and general management principles. *Obstet Gynecol.* 2009;114(1):192-202. <https://doi.org/10.1097/AOG.0b013e3181aef106>
18. Cramp AG, Bray SR. A prospective examination of exercise and barrier self-efficacy to engage in leisure-time physical activity during pregnancy. *Ann Behav Med.* 2009;37(3):325-334. <https://doi.org/10.1007/s12160-009-9102-y>

19. Cramp AG, Bray SR. Pre- and postnatal women's leisure time physical activity patterns: a multilevel longitudinal analysis. *Res Q Exerc Sport*. 2009;80(3):403-411. <https://doi.org/10.1080/02701367.2009.10599578>
20. Bauer PW, Pivarnik JM, Feltz DL, Paneth N, Womack CJ. Validation of an historical physical activity recall tool in postpartum women. *J Phys Act Health*. 2010;7(5):658-661.
21. Schulz LO, Harper IT, Smith CJ, Kriska AM, Ravussin E. Energy intake and physical activity in Pima Indians: comparison with energy expenditure measured by doubly-labeled water. *Obes Res*. 1994;2(6):541-548.
22. American College of Obstetricians and Gynecologists. ACOG Committee Opinion No. 650: physical activity and exercise during pregnancy and the postpartum period. *Obstet Gynecol*. 2015;126(6):e135-e142. <https://doi.org/10.1097/AOG.0000000000001214>
23. Pescatello LS, American College of Sports Medicine. *ACSM's Guidelines for Exercise Testing and Prescription*. 9th ed. Philadelphia: Wolters Kluwer/Lippincott Williams & Wilkins Health; 2014.
24. Ainsworth BE, Haskell WL, Whitt MC, et al. Compendium of physical activities: an update of activity codes and MET intensities. *Med Sci Sports Exerc*. 2000;32(9 Suppl):S498-S504.
25. Ainsworth BE, Haskell WL, Herrmann SD, et al. 2011 compendium of physical activities: a second update of codes and MET values. *Med Sci Sports Exerc*. 2011;43(8):1575-1581. <https://doi.org/10.1249/MSS.0b013e31821ece12>
26. Haskell WL, Lee I-M, Pate RR, et al. Physical activity and public health. Updated recommendation for adults from the American College of Sports Medicine and the American Heart Association. *Circulation*. 2007;116(9):1081-1093.
27. Knowlton JR, Hanson J, May L. Poster 23 exercise prescription for improved heart rate variability during pregnancy. *Phys Med Rehabil*. 2014;6(9):S189. <https://doi.org/10.1016/j.pmrj.2014.08.422>
28. May L, Terry M, Drake W, Suminski R. Effects of exercise during pregnancy on childhood heart measures. *J Cardiobiology*. 2014;S(1):5.
29. Crankshaw DJ, O'Brien YM, Crosby DA, Morrison JJ. Maternal body mass index and spontaneous contractility of human myometrium in pregnancy. *J Perinatol*. 2017;37(5):492-497. <https://doi.org/10.1038/jp.2016.271>
30. Helmreich RJ, Hundley V, Varvel P. The effect of obesity on heart rate (heart period) and physiologic parameters during pregnancy. *Biol Res Nurs*. 2008;10(1):63-78. <https://doi.org/10.1177/1099800408321077>
31. Di Mascio D, Magro-Malosso ER, Saccone G, Marhefka GD, Berghella V. Exercise during pregnancy in normal-weight women and risk of preterm birth: a systematic review and meta-analysis of randomized controlled trials. *Am J Obstet Gynecol*. 2016;215(5):561-571. <https://doi.org/10.1016/j.ajog.2016.06.014>
32. Sohnchen N, Melzer K, de Tejada BM, et al. Maternal heart rate changes during labour. *Eur J Obstet Gynecol Reprod Biol*. 2011;158(2):173-178. <https://doi.org/10.1016/j.ejogrb.2011.04.038>
33. Annunziata ML, Tagliaferri S, Esposito FG, et al. Computerized analysis of fetal heart rate variability signal during the stages of labor. *J Obstet Gynaecol Res*. 2016;42(3):258-265. <https://doi.org/10.1111/jog.12908>
34. Lim J, Kwon JY, Song J, Choi H, Shin JC, Park IY. Quantitative comparison of entropy analysis of fetal heart rate variability related to the different stages of labor. *Early Hum Dev*. 2014;90(2):81-85. <https://doi.org/10.1016/j.earlhumdev.2013.12.007>
35. Lawrence A, Lewis L, Hofmeyr GJ, Dowswell T, Styles C. Maternal positions and mobility during first stage labour. *Cochrane Database Syst Rev*. 2009;2:CD003934. <https://doi.org/10.1002/14651858.CD003934.pub2>
36. Ouzounian JG, Elkayam U. Physiologic changes during normal pregnancy and delivery. *Cardiol Clin*. 2012;30(3):317-329. <https://doi.org/10.1016/j.ccl.2012.05.004>
37. Almeida MB, Araújo CGS. Effects of aerobic training on heart rate. *Rev Bras Med Esporte*. 2003;9(2):113-120.
38. Dixon EM, Kamath MV, McCartney N, Fallen EL. Neural regulation of heart rate variability in endurance athletes and sedentary controls. *Cardiovasc Res*. 1992;26(7):713-719.
39. Roldan O, Perales M, Mateos S, Barakat R. Supervised physical activity during pregnancy improves fetal cardiac response. *Int J Med Sport Phys Act*. 15(60):757-772.
40. Caspersen CJ, Powell KE, Christenson GM. Physical activity, exercise, and physical fitness: definitions and distinctions for health-related research. *Public Health Rep*. 1985;100(2):126-131.

How to cite this article: McDonald S, Satterfield NA, May LE, Newton ER, Livingston J, Fang X. Influence of maternal exercise on fetal heart response during labor and delivery. *Health Sci Rep*. 2018;1:e81. <https://doi.org/10.1002/hsr2.81>