Influence of Exercise Mode on Maternal, Fetal, and Neonatal Health Outcomes:

The ENHANCED by Mom Project

by

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The extent of the health benefits of exercise during pregnancy is just beginning to be explored and developed. The purpose of this study was to compare the effects of aerobic and circuit training throughout pregnancy on maternal, fetal, and neonatal health outcomes. We hypothesized that we would find: (1) managed gestational weight gain (GWG), decreased body fat gain, and decreased maternal resting heart rate (RHR) in women throughout pregnancy as follows: aerobic training group = circuit training group > control group; (2) increased stroke volume (SV), ejection fraction (EF), and cardiac output (CO) at 34 weeks in fetuses exposed to maternal exercise training with greatest differences in the aerobic training group = circuit training group > control group; and (3) no differences in fetal anatomical cardiovascular measurements, fetal anthropometric measurements, or neonatal measurements of both exercising groups compared to controls. Participants completed three 45 minute sessions weekly from 16 weeks gestational age (GA) to 36 weeks GA of aerobic or circuit training, with controls completing monthly measurements and breathing exercises. We measured maternal RHR and blood pressure (BP) at each exercise session, maternal body composition monthly, 34 week fetal anthropometric and heart measures, and obtained neonatal measures at birth. Statistical analyses included t-tests, ANOVAs, and MANOVAs. Participants (n=15) were similar in age, parity, and pre-pregnancy body mass index (BMI), with a diversity of pre-pregnancy activity levels. All

groups had similar GWG and change in BMI throughout gestation. The aerobic training (AT) group gained significantly less body fat % throughout gestation relative to the circuit training (CT) (p=0.04) and control (p=0.03) groups. No differences were found between groups for change in RHR or diastolic BP (DBP). Exercising women experienced less of an increase in resting SBP relative to controls (p=0.01). Pre-training serum lipid levels were similar between groups. At the post-training measurement, the CT group had higher levels of total cholesterol and high density lipoprotein (HDL) cholesterol relative to the AT and control groups. The CT group had trends of a greater change in TC and low density lipoprotein (LDL) cholesterol throughout gestation relative to the AT and control groups. No differences were found between groups for fetal anthropometric measures, anatomical heart measures, or left ventricular (LV) physiological heart measures of SV, EF, and CO at 34 weeks GA. Fetuses exposed to CT had significantly increased right ventricular (RV) SV (p=0.03), with a trend towards increased RV EF relative to control fetuses (p=0.06). No differences were found in fetal RV CO between groups. However, there were trends for fetuses exposed to maternal exercise training to have greater CO relative to control fetuses. No differences were found between groups for neonatal birth weight, birth length, 1 min APGAR scores, and 5 min APGAR scores. Neonates exposed to CT had significantly increased (p=0.03) Ponderal Index (PI) compared to controls. Based on recommended exercise guidelines by the American Congress of Obstetrics and Gynecology (ACOG), these results suggest that 1) AT during pregnancy decreases body fat gain and improves maternal heart health, 2) CT during pregnancy improves fetal heart function and development, and 3) different types of exercise do not adversely affect growth and may impact neonatal body composition. Therefore, in order to maximize maternal and fetal benefits, it seems best to perform both aerobic and strength training during pregnancy.

Influence of Exercise Mode on Maternal, Fetal, and Neonatal Health Outcomes:

The ENHANCED by Mom Project

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by

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CHAPTER 1 – INTRODUCTION

The health benefits of exercise have long been understood by researchers and the general population. However, the extent of those benefits in special populations, such as pregnant women, is just beginning to be explored and developed. Pregnancy is a time of great change physically, emotionally, and mentally for a woman. For years, pregnant women were instructed by their physicians to avoid exercise due to the potential for harm to the developing fetus. However, as current research is beginning to demonstrate, aerobic exercise is safe and beneficial for the expectant mother,[1,3,5,6,34,79] contributing to improved cardiovascular health,[5,22,32] management of gestational weight gain (GWG),[38,77,81,90,91] and prevention of chronic diseases.[5] Current research has also concluded that maternal aerobic exercise may be beneficial for the cardiovascular system of the developing fetus.[7,10,33,35,52,64,65,66,95] However, the extent of these benefits in the developing fetal heart has not been sufficiently investigated. Neonatal growth is also positively affected by maternal aerobic exercise, resulting in decreased amounts of body fat and maintenance of normal weight and other morphometrics measured at birth.[24,27] The American College of Sports Medicine (ACSM), the American Congress of Obstetricians and Gynecologist (ACOG), the Society of Obstetricians and Gynecologists of Canada (SOGC), and the Canadian Society of Exercise Physiologists (CSEP) have published guidelines for exercise during pregnancy and the postpartum period.[3,5,6,34] Each of these guidelines provides similar recommendations for aerobic exercise during pregnancy, including recommendations for normal weight (NW) as well as overweight (OW) and obese (OB) individuals.

Unlike aerobic exercise, little research has been completed acknowledging the influence and possible health benefits associated with a combination of aerobic and resistance training on maternal health during pregnancy. The increased interest of women to engage in both types of exercise training warrants a better understanding of the effects it may have on weight

management, cardiovascular functioning, and overall health. Furthermore, research has not been completed on the fetal responses or adaptations as a result of exposure to acute or chronic maternal circuit training throughout pregnancy. Studies to date have focused on neonatal outcomes, reporting that birth weight does not differ between exercising and control groups.[48,87] Because of the increased popularity of this mode of training among pregnant women, it is essential to identify the health benefits to the fetus and neonate, especially regarding cardiovascular function and development. Logically, if aerobic and resistance exercise programs individually are safe for the pregnant woman and her fetus, then a combination program would also be safe. Clearly, more research is needed to ensure its efficacy for the mother and the fetus during pregnancy.

Consequently, there is limited evidence addressing OW or OB women beginning an exercise program during pregnancy. Research to date shows no increased risk of adverse health outcomes for an OW or OB mother or her fetus due to participation in aerobic exercise.[31,32,73,75] These studies have focused on management of gestational weight gain (GWG), safety and efficacy of exercise, and development of exercise guidelines in OW and OB pregnant women. However, research has not thoroughly examined chronic maternal, fetal, or neonatal cardiovascular adaptations as a result of circuit training during an OW/OB pregnancy. Non-pregnant OW and OB women have increased health benefits from beginning a regular exercise program, whether aerobic or strength oriented.[31,32,36,73,79,86,101,102] Since research has shown that exercise responses in NW pregnant populations is similar to normal-weight non-gravid women, one can extrapolate that the benefits for OW and OB pregnant women would also be similar to their non-gravid counterparts.

The purpose of this study was to compare the effects of aerobic and circuit training throughout pregnancy on maternal, fetal, and neonatal health outcomes in NW, OW, and OB women. We hypothesized that we would find: (1) managed GWG, decreased body fat gain, and decreased maternal resting heart rate in women throughout pregnancy as follows: aerobic trained group = combination training group > control group; (2) increased stroke volume, ejection fraction, and cardiac output at 34 weeks in fetuses exposed to maternal exercise training with greatest differences in the aerobic trained group = combination training group > control group; and (3) no differences in fetal anatomical cardiovascular measurements, anthropometric measurements, or neonatal measurements (i.e. birth length and weight) of both exercising groups compared to controls.

Definitions of Key Terms:

Normal Weight (NW) = a pre-pregnancy BMI of 18.5-24.9 in the adult population

Overweight (OW) = a pre-pregnancy BMI of 25-29.9 in the adult population

Obese (OB) = a pre-pregnancy BMI of 30-34.9; class 1 obesity per ACSM classification

Previously Sedentary = women who did not participate in regular physical activity (i.e. moving body accompanied by increased heart rate) for three or more times per week for 30 minutes or more each session, prior to pregnancy

Previously Active = women participating in regular physical activity for 3 or more times per week for 30 minutes or more each session, prior to pregnancy

Exercise Testing = a single date/visit during which treadmill and 1 repetition maximum testing occurs in order to set a target heart rate zone and external load for exercise training

Exercise Training = exercise program incorporating FITT principle (frequency, intensity, type, and time of activity) over an extended time period (i.e. 25 weeks)

Aerobic training (AT) = cardiovascular exercises completed on aerobic exercise machines with pre-determined resistance and speed settings for achieving and maintaining an individual's target heart rate zone

Circuit training (CT) = combination of aerobic and strength training (exercises completed on Cybex machines, with resistance bands, or dumbbells) into one inclusive exercise regimen

Acute measurements = those measurements taken during a single exercise session; a response to immediate exercise training

Chronic measurements = those measurements taken at rest between the exercise sessions; an adaptation to exercise training

Gestational weight gain (GWG) = difference in weight gained during pregnancy; measured as 36 weeks gestation weight minus self-reported pre-pregnancy weight

Body Composition = amount of fat mass vs. fat free mass as determine by skinfold measurement and associated body density and body fat percent equations

The purpose of this study was to compare the effects of aerobic and circuit training throughout pregnancy on maternal, fetal, and neonatal health outcomes in NW, OW, and OB women. The contents of this chapter will expound on the available literature and its applicability to the aim of the current study. Topics discussed include: guidelines for aerobic exercise during pregnancy, maternal and fetal responses to aerobic exercise, offspring measures related to aerobic exercise, maternal responses to circuit training, and fetal responses to other training modes during pregnancy.

Guidelines for Aerobic Exercise

The recommendations for aerobic exercise prescription during pregnancy published by the ACSM, ACOG, SOGC, and CSEP fully agree and cross-reference one another. These recommendations begin with clearance by a physician to participate in exercise. If a pregnant woman is healthy and has a low-risk pregnancy (i.e. no contraindications for exercise as listed in Table 3), then she should participate in moderate intensity aerobic exercise for at least 30 minutes most days of the week, with a goal of 150 minutes per week.[1,3,5,6,34] Previously sedentary, OW, and OB pregnant women are encouraged to begin with 15 minutes per exercise bout and gradually increase to the recommended 30 minutes.[1,3,5,6,34,79] Moderate intensity has been defined as approximately 60-80% of maximum heart rate (HR_{max}), 12-14 on the Borg scale rating of perceived exertion (RPE), or by using the "talk test," which means being able to converse while exercising without feeling short of breath.[3,6,26,34,73,74] Since pregnancy involves numerous physiological and anatomical changes, target heart rate (THR) zones for non-gravid women are not sufficient to meet the physiological demands of pregnancy. Due to this physiological phenomenon, THR ranges for NW, OW, and OB pregnant women have been

developed and are listed in Table 1.[34,73,74] The goal of exercise during pregnancy is to maintain

or increase fitness level and avoid maximal exertion.[34,63,80] To achieve this goal, it is currently

recommended that pregnant women engage in aerobic exercises such as walking, seated cycling,

and swimming.[1,3,6,25,34] Pregnant women should avoid activities that increase their risk of losing

balance or could result in fetal trauma, such as ball-sports and recreational activities like skiing,

biking outside, and horseback riding.[1,3,6,25,34] Overall, these recommendations are similar to those

for non-gravid populations as published by the ACSM.[3]

Modified Target Heart Rate Ranges for Pregnant Women		
Age	*Normal Weight*	*Overweight & Obese*
< 20 years old	140-155	
20-29 years old	135-150	110-131
30-39 years old	130-145	108-127
> 40 years old	125-140	

Table 1. Modified target heart rate zones developed for normal, overweight, and obese pregnant women based on pre-pregnancy weight and BMI.

Maternal Responses to Aerobic Exercise

Pregnant women engaging in aerobic exercise receive similar health benefits as non-

pregnant women.[36,41,86] These benefits range from improvements in cardiovascular function,

metabolic function, weight management, and mental health functions acutely and after prolonged

periods of exercise training. Though gravid women experience similar benefits to exercise as the

adult population, their acute responses to exercise are slightly different when compared to pre-

pregnancy values because of the physiological and anatomical changes associated with

pregnancy (Table 2).[3] As in non-pregnant populations, pregnant women of all BMI

classifications experience adaptations, such as decreases in resting heart rate (RHR) and

increases in cardiac output (CO), in response to chronic aerobic exercise.[22,23,25,32] Blood pressure

(BP) does not significantly change throughout the course of pregnancy between women who

exercise and those who do not, regardless of the level of intensity.[22,67] Santos et al[92] found that

aerobic submaximal exercise capacity is increased in OW pregnant women after an aerobic

exercise training program. The regulation of insulin, glucose, and blood lipids is also improved

in pregnant women who participate in aerobic exercise,[5,22,23,25] as in non-gravid populations.[86]

Body composition measures, such as decreased fat deposition, also change during pregnancy in

response to aerobic exercise similar to the non-pregnant population.[22,23,25,36,41,86] GWG is much

more variable for OW and OB pregnant women participating in an exercise program.[20,34,36] In

addition, previously sedentary women who begin an exercise program during pregnancy

experienced improved cardiovascular function, improved body composition, and less weight gain

during pregnancy, thus decreasing their risk of developing gestational diabetes mellitus (GDM)

and hypertension.[73]

Physiologic Responses to Acute Exercise During Pregnancy Compared with Pre-Pregnancy	
Oxygen Uptake	Increase
Heart Rate	Increase
Stroke Volume	Increase
Cardiac Output	Increase
Tidal Volume	Increase
Minute Ventilation	Increase
Ventilatory Equivalent for Oxygen	Increase
Ventilatory Equivalent for Carbon Dioxide	Increase
Systolic Blood Pressure	No Change/Decrease
Diastolic Blood Pressure	No Change/Decrease

Table 2. Adopted from *ACSM's guidelines for exercise testing and prescription*. 8th ed. Philadelphia (PA): Wolters Kluwer and Lippincott Williams & Wilkins; 2010. p. 184.

Ruchat et al[91] utilized a light intensity and moderate intensity aerobic exercise program

coupled with a nutrition intervention in NW pregnant women. Although participants gained

excess weight prior to the start of this intervention, women in the exercise groups gained

significantly less weight throughout the entire course of their pregnancy than controls. Despite

this finding in the exercising groups, neonate weight, length, and BMI did not significantly differ

between groups.[91] Mottola et al[75] employed a similar exercise and nutrition intervention in OW

and OB pregnant women. No significant differences were found for total weight gained between the groups.[75] The amount of weight gained over the course of the pregnancy was within the acceptable range and not in excess, according to Institute of Medicine (IOM) guidelines.[2]

Management of GWG is important in preventing the development of GDM and hypertension in pregnancy, preventing delivery complications and adverse fetal outcomes, and decreasing the amount of weight retained post-partum.[5,41,46,71,73,75,81,91] Rossner[90] found that weight gain during pregnancy was the most significant predictor of weight retention 1 year postpartum. Weight retention can have adverse effects for the woman, increasing her susceptibility to various disease states, as well as adverse fetal health outcomes in future pregnancies. Edwards et al[38] reported that excess GWG may have greater consequences for neonatal health than maternal health in NW, OW, and OB pregnant women. Oken et al[81] further supported this claim, finding that excess GWG related directly to infant and childhood weight statuses. They found that excess GWG resulted in increased child adiposity at age 3 in NW, OW, and OB pregnant women.[81] Thus, the management of weight gained during pregnancy is important to improving maternal, neonatal, and childhood health and well-being.

These improvements in maternal health during pregnancy contribute to overall improved health post-partum, decreased risk of adverse conditions, and improved outcomes in future pregnancies. Aerobic exercise positively influences pregnancy outcome by decreasing complications for both mother and baby during labor and delivery, including a decreased need for Cesarean section delivery and decreased hospitalization time for maternal recovery.[48,49,87] Because pregnant women respond and adapt to exercise in a similar manner, the ensuing health benefits are likely to be similar regardless of weight classification and parity.

Fetal Responses to Aerobic Exercise

Previous research has shown fetal adaptations in response to maternal aerobic exercise including heart rate modulation,[64,65,66,99] development, and safety throughout maternal exercise bouts. Szymanski and Satin[99] monitored fetal heart rate (HR) before, during, and after single moderate and vigorous intensity exercise sessions. Fetal HR increased post-exercise in both groups, but did not exceed normal limits.[99] Ultrasound was also used to monitor the fetus before and after exercise sessions with no adverse outcomes noted.[99] These results indicate that acute maternal aerobic exercise of moderate or vigorous intensity is tolerated by the fetus. Other studies have also reported no signs of fetal distress in response to acute maternal aerobic exercise. Kennelly et al[52] measured fetal HR and heart rate variability (HRV) before and after a single maternal aerobic exercise test in OW pregnant women. No significant increases or decreases in fetal HR occurred during the exercise test.[52] However, after exercise, fetal HRV was significantly different from pre-exercise values, with a greater range observed.[52] These results suggest that a single bout of high intensity maternal aerobic exercise does not increase the risk of fetal distress. Clapp et al[21] measured amniotic erythropoietin levels to determine if regular maternal aerobic exercise throughout pregnancy induces a fetal hypoxic effect. Results indicated that erythropoietin levels were not significantly different between exercising women and non-exercising controls, further suggesting that the fetus is not in danger of chronic hypoxia or bradycardia as a result of chronic maternal aerobic exercise.[21]

Other physiological functions, such as stroke volume (SV), ejection fraction (EF), and cardiac output (CO) have been measured in utero, but have not been linked to levels and type of maternal exercise. SV, EF, and CO are all used for determining inotropic status and function of the fetal heart as it is developing.[96] The literature to date regarding these measures has focused

on determining reference ranges for SV, EF, and CO of healthy fetal hearts.[72,96] However, these studies have not included maternal exercise as a variable and its ensuing effects on fetal cardiovascular development and function. While a plethora of research has determined that maternal aerobic exercise is safe and beneficial to the fetal heart in regards to HR and HRV,[25,26,64,65,66,68] a better understanding of the effects on fetal physiological cardiovascular development and function is warranted.

Neonatal Measures Related to Maternal Aerobic Exercise

Multiple studies have found that neonates are not adversely affected by maternal aerobic exercise throughout pregnancy.[24,26,27,47,48,87] Outcome measurements have included birth weight, Ponderal index (PI), head circumference (HC), and 1 and 5 minute APGAR scores. Two studies completed by Clapp[24] and Clapp et al[27] reported that, at birth, neonates of exercising mothers weighed less due to less body fat percentage and total body fat mass than neonates of controls. However, there was no significant difference found in lean body mass between the neonates of each group.[24,27] Szymanski and Satin[99] found that birth weight was not significantly different between neonates of exercising pregnant women and controls. Ruchat et al[91] found that offspring of NW pregnant women who participated in an exercise and nutrition intervention did not significantly differ in regards to birth weight and BMI among maternal intervention groups (light intensity, moderate intensity, and control). A similar study employing OW and OB pregnant women also found that neonatal birth weight did not differ significantly between OW and OB women or between exercising women and matched controls from a local medical database.[75] Each of these studies provides evidence that neonates of exercising pregnant women, of any weight classification, are likely to have a normalized birth weight.

In the aforementioned study completed by Clapp[21] where birth weight was less in exercising women compared to controls, neonate PI was also decreased. In a similar study, Clapp[25] found that PI and HC were similar between exercising and control groups. In a follow-up study of exercising women only, Clapp[26] found that neonate PI was increased in those participating in high intensity exercise early in pregnancy followed by low intensity later in pregnancy compared to those participating in moderate intensity exercise throughout pregnancy or low intensity early followed by high intensity exercise later in pregnancy. Neonate HC was similar between these three exercising groups. These measurements indicate that neonates of exercising women are developmentally different than those of controls. A plethora of studies have found that neonate 1 and 5 minute APGAR scores are similar between exercising and control groups with scores greater than 8 generally documented for both.[25,26,47,48,87] This indicates that the neonates are healthy at birth.

Maternal Responses to Circuit Training

The combination of aerobic and resistance training has become more popular among healthy, non-gravid populations, extending into pregnant women. Aerobic training is known to improve cardiovascular and pulmonary health while resistance training results in increased muscular strength and endurance with improvements in body composition.[4] Research on the acute responses and chronic adaptations in maternal, fetal, and neonatal health of combining these modes of exercise has not been sufficiently addressed during pregnancy.

Acute responses of maternal health due to participation in circuit training while pregnant have not been reported. However, non-gravid participants in a single session of circuit training experienced decreased systolic and diastolic BP, stroke volume, and cardiac output and increased

systemic vascular resistance and HR compared to controls, acute aerobic training only, and acute resistance training only.[100]

Because aerobic exercise alone is safe and efficacious during pregnancy, ensuring individual responses to resistance exercises completed within a circuit is warranted. Preliminary studies have shown that acute resistance training can be safe and efficacious for the mother and her unborn child.[8,63,73,80] Avery et al[8] measured maternal HR and BP in response to individual strength exercises during the third trimester. The measured responses to strength training in pregnant women were similar to those of non-pregnant controls, with no differences in BP at rest and during each exercise, while HR was only elevated in pregnant women.[8] O'Connor et al[80] also reported no significant difference in maternal BP before and after acute maternal resistance training of 6 different strength exercises. This unaltered measurement of BP before and after acute resistance exercise during pregnancy is the same as noted in response to acute aerobic exercise.[22,67] Therefore, participation in a single session combining both aerobic and resistance exercises into a circuit program would not place undue physiological stress on the mother.

Few studies have measured maternal chronic adaptations and health outcomes in response to circuit training during pregnancy. A study by Hall and Kaufmann[48] explored pregnancy outcomes after a combination training exercise regimen throughout pregnancy. This regimen consisted of a 3-5 minute warm-up, followed by individually prescribed strength and flexibility exercises, ending with a 1-2 mile cycling workout. Exercise groups were divided into low, medium, and high according to the number of exercise sessions completed throughout the course of pregnancy. Women who completed more exercise sessions were less likely to have a Cesarean section than women who exercised less or not at all (Med/Hi > Low/Control). Additionally, women who exercised spent less time in the hospital after delivery compared to

non-exercise controls. Price et al[87] measured cardiorespiratory fitness, strength, and flexibility in OW pregnant women participating in a circuit training program throughout the 2nd and 3rd trimesters. At each testing session (every 6 weeks from 12 wks gestational age (GA) to 8 wks postpartum), the exercising groups had higher cardiorespiratory fitness, measured by power produced during a 2 mile walk, than controls.[87] Exercising pregnant women had significantly higher strength, measured by a 7kg lift test, than controls at each measurement from 18 weeks GA to 8 weeks postpartum.[87] Flexibility measures were not different between groups. Fewer women in the exercise group delivered via Cesarean section than controls and time to recovery postpartum was significantly shorter as well .[87] Similarly, non-gravid women also experience increased VO_2max and muscular endurance after 12 weeks of circuit training.[51]

It is important to understand the effects of resistance training individually throughout pregnancy as the pregnant woman will complete strength and aerobic exercises within a given circuit training regimen. O'Connor et al[80] further examined maternal resting BP in response to a 12 week, low-to-moderate intensity resistance training program in NW and OW women without previous experience in strength training. The average external load increased progressively over the 12 week period, which suggests an increase in maternal strength over time, although no assessments were completed to substantiate this claim. There was also no significant change in maternal resting BP noted from the beginning to the end of the 12 week program.[80] A case study completed in a single obese pregnant woman investigated the use of moderate intensity progressive resistance training of upper and lower body exercises throughout the 2nd and 3rd trimesters.[16] Over the course of the program, the participant gained lean body mass, lowered her BMI, and increased training volume by 58%.[16] It appears from these results that moderate intensity progressive resistance training throughout pregnancy is safe and beneficial to maternal

health. Similarly, Barakat et al[9] reported no difference in maternal GWG or type of delivery in NW pregnant women in response to chronic light intensity resistance training. Since resistance training is safe and efficacious for improvements in maternal health as an independent exercise regimen, it can be assumed that its combination with aerobic training into a circuit training regimen would also be safe and beneficial.

Fetal and Neonatal Responses to Other Training Modes

Very few studies have researched the effects of maternal circuit training on fetal and neonatal health, focusing primarily on birth outcomes. No studies to date have assessed fetal anthropometric or cardiovascular measurements as a result of exposure to maternal circuit training. Hall and Kauffman[48] found no significant differences in birth weight of neonates among groups. However, neonates of women who completed the most exercise sessions had higher 1 and 5 minute APGAR scores. Price et al[87] also reported no differences in birth weight between exercising and control groups. Although little has been reported regarding acute or chronic fetal and neonatal health measures in response to maternal circuit training, based on the available data this type of exercise is also safe during pregnancy.

Similar to studies looking at the effects aerobic exercise individually on fetal and neonatal outcomes, Avery et al[8] measured fetal HR responses before, during, and after individual maternal resistance exercises, with no change in fetal HR observed. This study concluded that the fetus tolerates acute maternal strength exercises and that the fetus is not in distress before, during, or after. Barakat et al[10] reported increased fetal HR in response to light intensity maternal resistance exercises. This finding indicates that the acute fetal HR response to maternal resistance exercises is normal and similar to that reported when exposed to acute maternal aerobic exercise. These results further substantiate the claim that the fetus is not at an increased

risk of distress or adverse health outcomes in response to acute maternal exercise, regardless of the type and intensity. Additionally, the fetus is not at an increased risk due to acute maternal strength exercises, further evidencing the safety and efficacy of participating in a combination of aerobic and strength exercises during pregnancy.

Since other studies have shown that pregnant populations have similar acute and chronic aerobic and resistance exercise training responses as non-gravid populations, one can postulate that pregnant populations will also benefit from the use of combination training regimens similar to their non-gravid counterparts. Although preliminary studies have shown that resistance training and aerobic training do not adversely affect fetal development individually, the effects on fetal and neonatal health outcomes from combining these two modes of exercise warrants further investigation.

Summary

Various types of physical activity throughout pregnancy have been proven safe and efficacious for the mother and her unborn child. Although a popular belief remains that women who are not previously active should refrain from beginning regular exercise during pregnancy, a plethora of research has refuted this claim. Moderate intensity aerobic exercise is safe and recommended for improving maternal cardiovascular health, managing GWG, and preventing subsequent chronic diseases post-partum. Moderate intensity aerobic exercise is also safe for the fetus and provides improvements in cardiovascular health without adversely affecting normal fetal development. Maternal aerobic exercise training also has positive effects on neonatal morphometrics by decreasing body fat mass and increasing lean mass. Circuit training has grown in popularity among non-gravid populations, extending into pregnant populations as well, but currently remains inadequately researched on its effects during pregnancy. More research is

needed to determine if this mode of exercise provides any short and/or long term benefits to maternal health. Furthermore, a scarce amount of research exists regarding the effects of circuit training on fetal health and development as well as any continued benefits for the neonate, especially with regards to cardiovascular development and function. Additionally, little research has focused on OW and OB pregnant women who, like their non-gravid counterparts, appear to significantly benefit from participation in a regular moderate intensity aerobic exercise program throughout gestation. The current study aims to address many of these unanswered questions by determining if various modes of exercise training throughout pregnancy provide different benefits to maternal, fetal, and neonatal health in NW, OW, and OB women of varying pre-pregnancy activity levels.

Participants

This study aimed to recruit women with singleton pregnancy who had received a physician's clearance to participate in physical activity; those that were previously sedentary or active; between the ages of 18 and 40; a pre-pregnancy body mass index (BMI) 18.5-34.9; gestational age ≤16 weeks; not currently using alcohol, tobacco, recreational drugs, or medications for mental health disorders; and not currently meeting any of the contraindications to exercise in pregnancy as outlined by the ACSM and SOGC guidelines (Table 3).[3,34] Participants with pre-existing type 1 or type 2 diabetes, hypertension, or other cardiovascular disease were also excluded from the study. Participants with any pre-existing diseases that can affect fetal development, such as HIV, AIDS, or lupus, were further excluded from the study. Any participant diagnosed with gestational diabetes mellitus (GDM) during the study would remain enrolled in the study, but their results would be analyzed separately from other participants.

Absolute Contraindications to Aerobic Exercise During Pregnancy	Relative Contraindications to Aerobic Exercise During Pregnancy
Hemodynamically significant heart disease	Severe anemia
Restrictive lung disease	Unevaluated maternal cardiac arrhythmia
Incompetent cervix/cerclage	Chronic bronchitis
Multiple gestation at risk for premature labor	Poorly controlled type I diabetes
Persistent second or third trimester bleeding	Extreme morbid obesity
Placenta previa after 26 weeks gestation	Extreme underweight (body mass index <12)
Premature labor during the current pregnancy	History of extremely sedentary lifestyle
Ruptured membranes	Intrauterine growth restriction in current pregnancy
Pregnancy induced hypertension	Poorly controlled hypertension/preeclampsia
	Orthopedic limitations
	Poorly controlled seizure disorder
	Poorly controlled thyroid disease
	Heavy smoker

Table 3. Contraindications to aerobic exercise during pregnancy. Adopted from *ACSM's guidelines for exercise testing and prescription*. 9th ed. Philadelphia (PA): Wolters Kluwer and Lippincott Williams & Wilkins; 2013.

Participants could be cleared and screened prior to 13 weeks gestation, but did not commence any exercise testing or training until 13 weeks gestation in order to avoid any prevalent bouts of morning sickness and spontaneous abortion characteristic of the first trimester. Informed written consent was obtained from each participant prior to enrollment. All protocols were approved by the East Carolina University Institutional Review Board.

Study Procedure

Study procedures are summarized in Figure 1. Prior to 16 weeks gestation women were recruited by brochures and physician office promotion at local obstetrics/gynecology (Ob/Gyn) clinics as well as a listserve email announcement sent to institutional faculty and staff. An inclusion and exclusion criteria card was used by Ob/Gyn clinic staff to inform eligible patients of the study and determine individual interest in participation. Study staff members also used this criterion to screen possible participants who requested more information regarding the study. Physician clearance, screening, informed consent, testing visit, and questionnaire were completed at or before 16 weeks gestation.

Between 13-16 weeks GA, participants completed informed consent, were enrolled in the study, and completed the initial testing appointment. Upon arrival, a non-fasting venous sample was collected, processed, and stored for later analysis of lipids prior to the start of exercise testing. All participants performed a modified Balke treadmill test in order to determine individual THR zones. To enhance participant retention, the content of each study group was explained to participants, allowing each to select which exercise training group they preferred to participate in. Participants in the circuit training (CT) group completed 1 repetition maximum (1RM) testing on Cybex machines after completion of the treadmill exercise test. Upon completion of pre-exercise testing, participants completed a modified physical activity

questionnaire (MPAQ) to determine pre-pregnancy activity levels. Participants in the CT group were instructed of the proper form for each exercise at their first scheduled session.

Exercise programs were modified within study parameters to participant preferences, choosing 3 days to attend supervised sessions between 7:00 a.m. and 7:00 p.m. Monday through Friday and 8:30 a.m. to 11 a.m. on Saturdays. Any additional exercise, which was encouraged for the aerobic training (AT) and CT groups, were unsupervised, at-home workouts. Resting HR and BP were assessed before and after each exercise session and exercise HR was monitored throughout exercise duration to maintain individual THR zones. Maternal anthropometric measurements of weight, height, circumferences, and skinfolds were assessed prior to the start of exercise every 4 weeks beginning at the 16th week of gestation. At 34 weeks gestation fetal weight and body morphometrics (i.e. circumferences and bone lengths) were assessed using fetal ultrasound during a scheduled visit at the East Carolina University (ECU) Ob/Gyn clinic. Anatomical heart measures were also assessed from which stroke volume (SV), ejection fraction (EF), and cardiac output (CO) were calculated. At 36 weeks gestation a second non-fasting maternal venous sample was collected prior to the start of exercise, processed, and stored for later analysis of lipids. The MPAQ was completed a second time after delivery to verify maternal activity levels throughout the duration of the study. Upon delivery, and with written informed consent of mothers, birth and delivery information was acquired including neonate gender, weight and length (to calculate Ponderal index), and APGAR scores.

Pre-Enrollment Events
- Clearance
- Recruitment/Screening
- Informed Consent

Maternal Measurements
- Weight
- BMI
- 4-site skinfold
- Circumferences

Final Measurements
- Lipid Profile
- MPAQ

Gestational Week: <13   13-16   16   20   24   28   32   34   36   Delivery

Enrollment Events
- Pre-Exercise Testing
- Lipid Profile
- MPAQ
- Group Assignment
- Initiate Exercise Program

Fetal Measurements
- Ultrasound
  - Anthropometrics
  - Heart Measures
  - Stroke Volume
  - Ejection Fraction
  - Cardiac Output

Birth Measurements
- Gender
- Weight
- Length
- APGAR Scores
- Ponderal Index

Figure 1. Schematic of study timeline.

Pre-Exercise Testing

Modified Balke Protocol. After enrollment aerobic exercise testing for all women was utilized

to determine THR ranges for individualizing participants' exercise prescription. VO$_2$peak testing

using a modified Balke protocol (Table 4) was used as validated and replicated by Mottola et

al.[72] Prior to the start of testing, the ParvoMedics TrueMax 2400 metabolic measurement system

was calibrated according to the manufacturer's instructions. Before every exercise test gas

calibration of a tank consisting of 16% oxygen, 4% carbon dioxide, and a nitrogen balance was

performed. The flow rate and flow meter sensor were then calibrated using a 3-liter syringe.

Prior to starting the test, participants had their height (in.) and weight (lbs.) recorded with typical

casual exercise clothing, excluding shoes. Standing resting BP and HR were also assessed. HR

was continuously monitored and recorded at the end of each stage using a Polar FS2C heart rate

monitor. Maternal BP, HR, and rating of perceived exertion (RPE) (Table 5)[18] were recorded in

the last 30 seconds of each stage. The test began with 5 minutes of gas collection at a resting

state while the participant stood on the treadmill followed by a 5 minute warm-up at 3.0 mph and

0% grade. Each stage was 2 minutes in duration. The first stage remained at the warm-up

settings. The treadmill grade was increased by 2% with each stage. If the participant had not

voluntarily terminated the test upon reaching a 12% grade, the speed was increased by 0.2 mph

each stage until an RPE of 15 was reached. Expired gases were collected and analyzed every 20

seconds by the ParvoMedics TrueMax 2400 metabolic measurement system. Participants were

not permitted to hold onto the treadmill handrails throughout the test unless re-attainment of

balance was necessary. The participant continued the test until she felt that she could no longer

continue, she experienced any symptoms requiring immediate cessation of exercise as outlined

by the ACSM,[3] or she reached an RPE of 15. A 5 minute cool down at 3.0 mph and 0% grade

commenced followed by 3-5 minutes of gas collection at a resting state while the participant

remained standing on the treadmill.

Modified Balke Protocol *(VO$_2$peak pre-exercise testing)*						
Stage	Minute	Speed (mph)	Grade (%)	HR (bpm)	BP	RPE
Warm-up	0-5	3.0	0			
1	0-2	3.0	0			
2	2-4	3.0	2			
3	4-6	3.0	4			
4	6-8	3.0	6			
5	8-10	3.0	8			
6	10-12	3.0	10			
7	12-14	3.0	12			
8	14-16	3.2	12			
9	16-18	3.4	12			
10	18-20	3.6	12			

Table 4. Modified Balke protocol for pre-exercise VO2peak testing. Adapted from Mottola et al. VO$_2$peak prediction and exercise prescription for pregnant women. *Med Sci Sports Exerc*. 2006;38(8):1389-1395.

Borg Scale for Rating of Perceived Exertion (RPE)	
6	
7	Very, very light
8	
9	Very light
10	
11	Fairly light
12	
13	Somewhat hard
14	
15	Hard
16	
17	Very hard
18	
19	Very, very hard
20	

Table 5. Borg RPE Scale. Adapted from Borg GA. Psychophysical bases of perceived exertion. *Med Sci Sport Ex*. 1982; 14: 377-81.

1 Repetition Maximum Testing (1RM). For the CT group only, after completion of the treadmill exercise test, 1RM testing[8] was used to determine appropriate external loads for Cybex exercise machines used in the resistance portion of the CT group's protocol. In order to decrease the risk of injury, this was also used as a time to instruct each participant on the proper form to be used throughout each exercise. The goal was to find a load that could be maintained throughout the set, within each participant's individualized THR range, while also maintaining proper form for each exercise in the assigned regimen. The RPE scale was used to maintain a moderate intensity rating of 12-14.

Questionnaire

The Modifiable Physical Activity Questionnaire (MPAQ) was used to assess maternal physical activity levels at enrollment and after delivery in order to a) determine activity levels of participants prior to the start of their respective exercise training protocol and b) verify the amount and type of exercise completed outside of the study protocol throughout pregnancy (i.e. control group not exercising aside from stretching or normal activities of daily living). This

questionnaire applies to physical, occupational, and leisure-time activities taking place over the past 12 months and was chosen based on its validity and reliability of use in pregnant populations as well as its ability to adequately assess activity levels.[30,55]

Exercise Protocol

All groups, including controls, began each exercise session with a 5 minute aerobic warm-up of low intensity (i.e. treadmill speed ≤3.0 mph) followed by their respective protocols. HR was monitored using a Polar FS2C heart rate monitor and maintained in the THR range determined by each participant's pre-exercise test, but not to exceed THR ranges validated for pregnant women.[31] Moderate intensity was maintained using the Borg scale of perceived exertion,[18] with the goal of 12-14 for moderate intensity, as well as the "talk test."

The aerobic training group (AT) performed aerobic exercise only using treadmills, ellipticals, or recumbent bicycles for a 45 minute workout. Treadmill speed was maintained at ≤3.0 mph, adjusting the percent grade to maintain the individual's pre-determined THR range. Elliptical and recumbent bike resistance and speed levels were adjusted as necessary throughout the study's duration to maintain the individual's pre-determined THR zone.

The circuit training group (CT) performed a circuit of aerobic and resistance exercises, devoting equal time to each, for a 45 minute workout. After the warm-up, participants rotated between 4.5 minutes of aerobic and resistance training (RT) exercises, for a total of 5 circuits. RT exercises were 1 set of 15 repetitions and aerobic training similar to the AT group. RT exercises consisted of seated Cybex machine exercises including leg extension, leg curl, shoulder press, chest press, triceps extension, and latissimus dorsi pull down. Dumbbells were used for bicep curls, lateral shoulder raises, and front shoulder raises. Resistance bands and dumbbells were also used as an alternative method for Cybex machine exercises if the participant was

unable to maintain proper form or experienced discomfort in the machine's positioning of the body. Core exercises were completed on an exercise ball or bench for stability or side-lying on a mat. Core exercises avoided supine positioning at all times and varied among participants based on level of comfort at the present stage of pregnancy, with all options being safe core exercises during pregnancy based on previous research findings.[85] An RPE of 12-14 was used to maintain moderate intensity during RT exercises.[80] Throughout the study's duration, each participant progressed accordingly with changes in the resistance and speed of AT exercises as well as increases in RT exercises. The continual switch between RT and AT exercises helped maintain the participant's HR in the appropriate THR range throughout the exercise duration to induce a training effect similar to the AT group.

The control group performed 45 minutes of various stretching, breathing, and flexibility exercises. Stretches targeted major muscle groups of the shoulders, triceps, legs, chest, and back. Breathing exercises combined stretches with inhalation and exhalation techniques.[78,93] Flexibility exercises consisted of transitions between stretches with controlled breathing techniques similar to low intensity yoga training. HR was maintained at a low level, below each participant's pre-determined THR range, not to exceed exertion levels above normal activities of daily living. A combination of seated, standing, and mat exercises was included.

Maternal Measurements

Serum lipid profiles were assessed at enrollment and 36 weeks gestation. Blood samples were acquired from the antecubital or cephalic vein into 1 tiger and 1 purple topped BD Vacutainer SST. Vacutainers were inverted 8 times for proper mixing of blood and vacutainer contents. Tiger topped serum vacutainers sat at room temperature for 30 minutes prior to centrifugation at room temperature. Purple topped plasma vacutainers containing the

anticoagulant EDTA were immediately centrifuged in a Fisher Scientific accuSpin 1R at 4 degrees Celsius. After centrifugation, plasma and serum samples were aspirated by use of pipette into a micro-vial for storage at -80 degrees Celsius until analysis.

Serum samples were thawed overnight prior to analysis of total cholesterol, high density lipoproteins (HDL) cholesterol, and triglycerides (TG) using a clinical blood analyzer (Beckman Coulter, version 5.3.05). The blood analyzer and the appropriate reagents were calibrated according to manufacturer's instructions prior to analysis of samples.[13,14,15] Serum was aspirated by use of pipette into vials to be loaded into the blood analyzer. Once the samples were loaded, they were programmed into the system and analyzed according to the manufacturer's protocols for total cholesterol,[13] HDL cholesterol,[14] and TGs.[15] Based on results of serum sample analyses, low density lipoprotein (LDL) cholesterol levels were calculated using the Friedwald equation (LDL = total cholesterol - HDL - TG/5) as validated previously.[45] All values were measured as milligrams per deciliter (mg/dL).

Body mass index (BMI) was calculated using BodyComp software (Version 3.05). As determined by the ACSM,[3] a pre-pregnancy BMI of 18.5-24.9 was used for the NW classification, 25.0-29.9 was used for the OW classification, and 30.0-34.9 was used for the OB classification. Weight and height at each measurement time were assessed in typical, casual athletic clothing without shoes. Weight was measured in pounds to the nearest 0.1 lb on a calibrated medical scale. Height was measured in inches to the nearest 0.25 inch. GWG was recorded in pounds to the nearest 0.1 lb as the difference in weight from 16 wks to 36 wks GA.

Skinfold measurements were assessed at four sites (triceps, subscapular, suprailiac, and thigh) with Harpenden skinfold calipers every 4 weeks, starting at 16 weeks gestation. All skinfolds were assessed on the right side of the body in a standing, relaxed state according to

standard ACSM procedures.[3] Locations were measured in the same rotational order twice so that the skin had ample time to return to its resting state. The calipers were placed midway between the crest and the base of the fold. The fold was held while the calipers were in contact with the skin for no more than 2 seconds before the reading was recorded. All measurements were to the nearest 0.2 mm, with the average of 2 trials taken. If the 2 trials were not within 2.0 mm, a third was taken to ensure accuracy of measurement. The triceps was a vertical fold over the posterior aspect of the upper arm, midway between the acromion process of the shoulder and the olecranon process of the elbow joint. The subscapular was a diagonal fold measured 1-2 cm below the inferior angle of the scapula. The suprailiac was also a diagonal fold measured in line with and just superior to the natural angle of the iliac crest of the pelvis, anterolateral to the mid-axillary line. The thigh was a vertical fold measured midway between the patella and the inguinal crease. The sum of the averages of the triceps, subscapular, and suprailiac folds were then placed into the Durnin[37] equation to estimate percent body fat as validated in pregnant populations by Miller and Ballor.[69]

Circumference measurements were assessed every 4 weeks, starting at 16 weeks gestation, using a Gulick measuring tape. All measurements were recorded in inches to the nearest 0.25 in., with the average of 2 trials taken. If the 2 trials were not within 0.5 in., a third was taken to ensure accuracy of measurement. The minimum waist was measured as the smallest circumference between the umbilicus and the xiphoid process.[3] Unilateral hips/thigh, mid-thigh, calf, arm, and forearm circumferences were also measured in inches in a rotational order according to the standardized procedures established by the ACSM.[3] Waist-to-hip ratios were calculated by dividing the minimum waist by the hips/thigh measurements.

Fetal Measurements

At 34 weeks gestation, an ultrasound was completed at a local Ob/Gyn clinic to assess fetal weight, body anthropometrics, and anatomical heart measures for the calculation of physiological heart measures. This procedure has been replicated and validated previously in healthy, normal pregnancies for accuracy of measurements.[72,96] After placing water based gel on the maternal abdomen, this technology uses high frequency sound waves to calculate fetal heart rate and visualize fetal anatomy. Fetal weight was estimated in grams. Fetal anthropometric measures of biparietal diameter (BPD), femur length (FL), and humerus length (HUM) were measured in millimeters. Head and abdominal circumferences were also measured in millimeters. Right and left ventricular diameters and widths were measured in millimeters. Heart physiological measures were calculated for both the right and left ventricle based on anatomical measurements assessed in the ultrasound. SV, measured in milliliters (mL) was calculated by subtracting the end diameter in systole from the end diameter in diastole. EF was calculated by dividing the SV by the end diameter in systole and multiplying by 100 for a percentage. CO, measured in mL, was calculated by multiplying SV and HR. The ultrasound was completed for all participants by the same blinded ultrasound technologist.

Neonatal Measurements

Neonatal measures of gender (M/F), birth weight (grams), birth length (cm.), and 1 and 5 minute APGAR scores were acquired from birth records after maternal consent. Ponderal index (kg/cm^3), a measure of neonate leanness similar to adult BMI, was calculated by the following formula: PI = 1000 [(mass in g)/(height in cm^3)].[89] All birth measurements were obtained by clinical staff members that were blinded to participant's respective groups.

Statistical Analyses

Data from participants not meeting adherence rates of 90% were excluded from statistical analyses. Alpha level was set *a priori* at $p < 0.05$ for all analyses. Independent t-tests were first completed to determine initial significance between exercising and control groups. Independent t-tests were also completed between NW and OW/OB participants to determine any initial significance. Univariate analyses of variance (ANOVA) and multivariate analyses of variance (MANOVAs) were completed on all variables between AT, CT, and control groups if initial significance was determined. Maternal measurements analyzed included GWG, change in % body fat, change in RHR, change in resting systolic BP (SBP) and diastolic BP (DBP), and change in lipid levels as a result of the exercise training program. The change in % body fat, RHR, resting SBP, and resting DBP was calculated as the measurement at 36 weeks GA minus the measurement at 16 weeks GA. Fetal measurements analyzed included body anthropometrics, anatomical heart measurements, SV, EF, and CO at 34 weeks GA. Neonatal measurements analyzed included birth weight, birth length, Ponderal index, and 1 and 5 minute APGAR scores. All analyses were completed using SPSS software (SPSS version 20, Chicago, 2009).

CHAPTER 4 – RESULTS

The participants in this study were 15 healthy female volunteers with low risk, singleton pregnancy that had been cleared by a physician to participate in exercise. Participants were similar in age, parity, and pre-pregnancy BMI classification, with each group containing an equal number of women from NW and OW/OB pre-pregnancy BMI classifications (Table 6). Participants were also equally diverse regarding pre-pregnancy activity level, education level, and income level (Table 6). All participants had a healthy pregnancy and none were diagnosed with GDM during the study. One participant from the CT group had decreased activity levels in the final 4 weeks of the study due to early onset of contractions and dilation.

Participant Demographics			
	CT Group (n=8)	AT Group (n=4)	Control Group (n=3)	Significance
Age	28.9 (±2.3)	29.8 (±6.4)	32.0 (±2.6)	NS
Parity	2.25 (±2)	1.75 (±1)	2.0(±0)	NS
Pre-Pregnancy BMI	24.1(±3.8)	26.3(±5.2)	24.4(±3.7)	NS
GWG	30.4(±8.9)	28.5(±13.9)	33.5(±9.6)	NS
Change in BMI	3.7(±1.8)	3.0(±1.8)	4.2(±1.1)	NS

Table 6. Participant Demographic Information. Values are reported as mean(±SD). Age (yrs); Pre-pregnancy BMI (kg/m^2); *GWG*, gestational weight gain (lbs.).

Maternal Measurements

All groups had similar GWG and change in BMI throughout pregnancy. There were no significant differences in BMI or body fat % measured between groups at each GA, with all groups progressively increasing in measures as GA increased (Figure 2). The AT group gained significantly less body fat % throughout gestation relative to the CT (p=0.04) and control (p=0.03) groups (Figure 3).
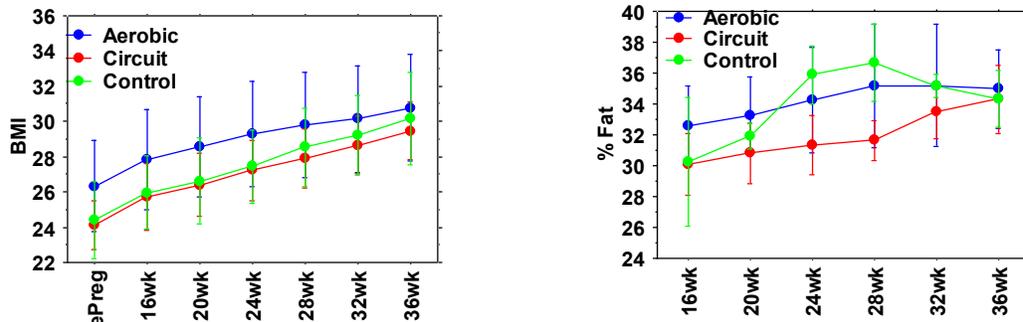
Figure 2. Change in BMI (left panel) and % body fat (right panel) throughout gestation. Aerobic n=4, Circuit n=8, Control n=3.
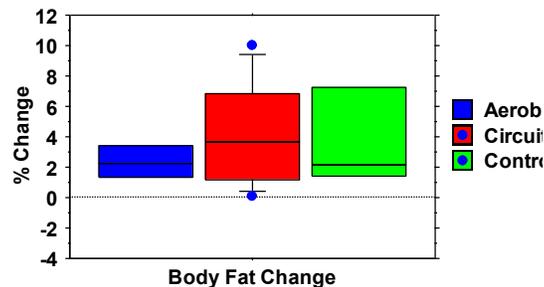

Figure 3. Change in maternal body fat %. Difference calculated as 36 wks GA - 16 wks GA. Aerobic n=4, Circuit n=8, Control n=3.

Although RHR increased throughout gestation, there were no significant differences between groups. There were no significant differences in resting SBP between groups at each GA, however, the exercisers experienced less of an increase in resting SBP (Figure 4, left) relative to controls (p=0.01). There was no significant difference in resting DBP at each GA or in the change in resting DBP (Figure 4, right) between groups.
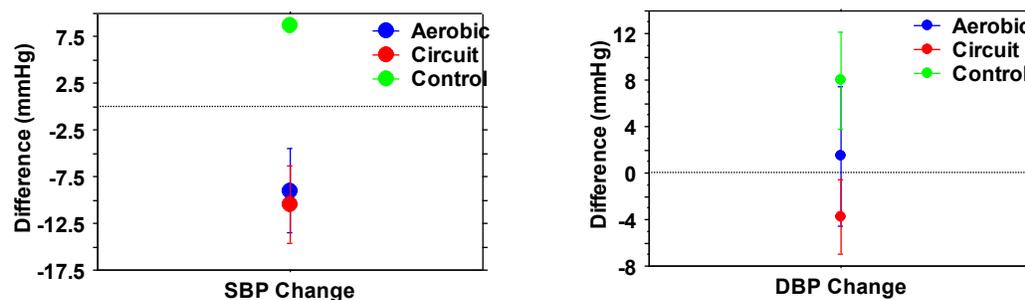
**Figure 4. Change in maternal resting SBP and DBP throughout gestation. Difference calculated as 36 wks GA - 16 wks GA. Aerobic n=4, Circuit n=8, Control n=3.**

Blood samples could not be acquired from one participant in the CT group. There was no significant difference in pre-training serum blood lipid levels between groups (Table 7). At post-training measurements (36 wk GA), the CT group had significantly higher levels of total

cholesterol (p=0.02) relative to controls, with trends for higher total cholesterol (p=0.06)

compared to the AT group (Figure 5). The CT group tended to have higher HDL cholesterol

levels post-training relative to the AT and control groups, which were similar to each other

(Figure 6). The CT group had trends of a greater change in TC and LDL cholesterol relative to

the AT group and controls (Figure 7).

Serum Blood Lipid Levels					
Pre-Training (13-16 wks GA)			*Post-Training (36 wks GA)*		
CT (n=7)	*AT (n=4)*	*Control (n=3)*	*CT (n=7)*	*AT (n=4)*	*Control (n=3)*
TC 188.3(±21)	185(±22.7)	180.3(±31.7)	281.7(±33.6)*	233.3(±29.2)	221.7(±16.6)
HDL 66.6(±17.9)	59.8(±12.2)	55.3(±7.3)	77.3(±18.3)	60.3(±7.6)	55.6(±24.5)
LDL 91.8(±24.4)	98.3(±11.7)	96.5(±24.1)	150.3(±35.9)	125.6(±27.5)	114(±10.1)
TG 149.9(±45.8)	134.3(±14.2)	143(±76.3)	270.7(±95.7)	236.5(±92.6)	260.3(±67)

Table 7. Pre- and post-training values of maternal serum blood lipid levels. Values are expressed as mean(+SD) in mg/dL. *CT*, circuit training group. *AT*, aerobic training group. *TC*, total cholesterol. *HDL*, high-density lipoportein. *LDL*, low-density lipoprotein. *TG*, triglycerides. * p<0.05 compared to Control.
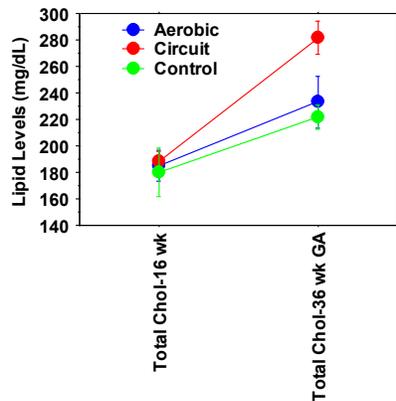

Figure 5. Serum total cholesterol (Total Chol) levels from pre-to post-training. Aerobic n=4, Circuit n=7, Control n=3.
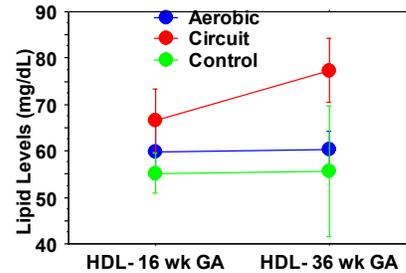

Figure 6. Serum high density lipoprotein (HDL) levels from pre- to post-training. Aerobic n=4, Circuit n=7, Control n=3.
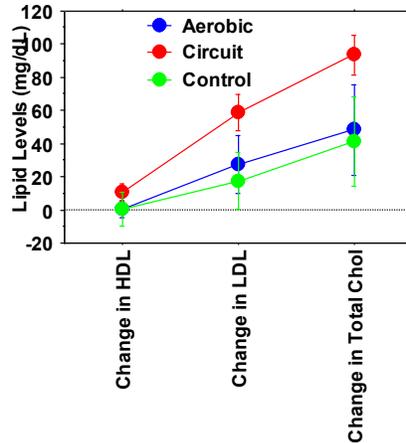
Figure 7. Change in maternal serum blood lipid levels throughout gestation. Difference calculated as post-training value (36 wks GA) - pre-training value (16 wks GA). Aerobic n=4, Circuit n=7, Control n=3. *HDL*, high density lipoprotein; *LDL*, low density lipoprotein; *Total Chol*, total cholesterol.

Fetal Measurements: Anthropometric

There was no significant difference in fetal morphometrics of biparietal diameter (BPD), head circumference (HC), abdominal circumference (AC), femur length (FL), or humerus length (HUM) between groups at 34 wks GA (Table 8). Fetuses exposed to AT tended to have larger BPD and HC compared to CT (p=0.05; p=0.06) and control (p=0.06; p=0.08) groups. Fetuses exposed to CT tended to have shorter humerus length relative to the control group (p=0.05).

	Fetal Anthropometric Measurements			
	CT (n=8)	*AT (n=4)*	*Control (n=3)*	*Significance*
BPD	**86.3(±3.9)**	**90.9(±2.1)**	**88(±0.5)**	**Trends**
HC	**311.6(±10.8)**	**324.9(±9.6)**	**310.8(±7.2)**	**Trends**
AC	318.7(±11.8)	319.3(±6)	319.4(±15.8)	NS
FL	67.3(±2.9)	67.2(±4.2)	69.7(±1.3)	NS
HUM	**58.1(±2.3)**	**60.9(±5.4)**	**61.5(±2.1)**	**Trends**

Table 8. Fetal anthropometric measures at 34 wk GA ultrasound. *BPD*, biparietal diameter. *HC*, head circumference. *AC*, abdominal circumference. *FL*, femur length. *HUM*, humerus length. Values are expressed as mean(+SD) in millimeters.

Fetal Measurements: Heart

There was no significant difference in fetal anatomical heart measures between groups at 34 wks GA. There was no significant difference in left ventricular (LV) physiological heart measures of SV, EF, and CO between group at 34 wks (Figures 8 and 9). The CT group fetuses had significantly increased right ventricular (RV) SV (Figure 8, left) compared to control fetuses (p=0.03). There was a trend towards increased RV EF (Figure 8, right) in CT fetuses relative to

control fetuses (p=0.06). There were no significant differences in fetal CO for LV or RV

between groups (Figure 9). However, there were trends for fetuses exposed to maternal exercise

training to have greater CO relative to control fetuses (Figure 9).
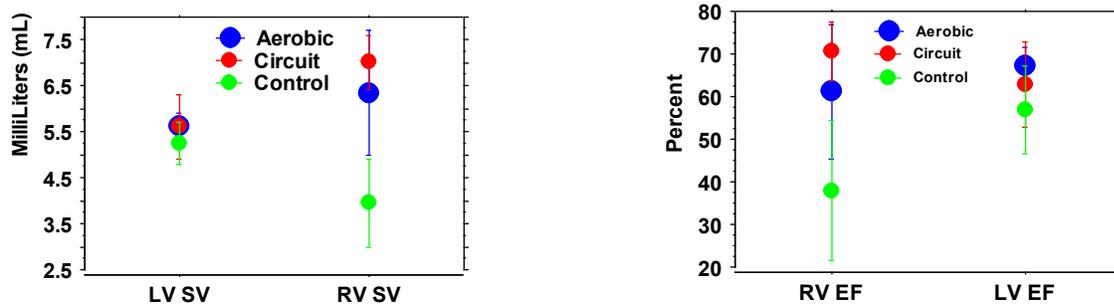
Figure 8. Left panel: fetal stroke volume (SV). Right panel, fetal ejection fraction (EF) at 34 wks GA. *LV*, left ventricle, Aerobic n=3, Circuit n=7, Control n=2. *RV*, right ventricle, Aerobic n=2, Circuit n=6, Control n=2.
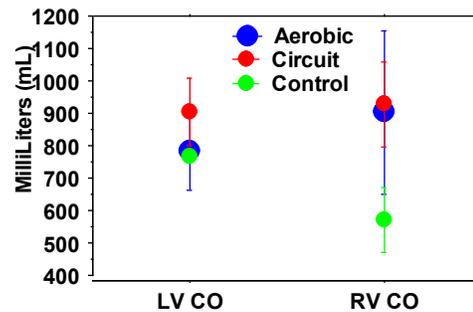
Figure 9. Fetal cardiac output (CO) at 34 wks GA. *LV*, left ventricle, Aerobic n=2; Circuit n=4; Control n=2. *RV*, right ventricle, Aerobic n=2; Circuit n=3; Control n=2.

Neonatal Measurements

There was no significant difference in birth weight, birth length, 1 min APGAR scores,

and 5 min APGAR scores between groups (Table 9). The CT neonates had significantly

increased (p=0.03) Ponderal Index compared to controls (Table 9).

	Neonatal Demographics		
	CT (n=8)	*AT (n=4)*	*Control (n=3)*
Birth Weight	3287(±401.7)	3602(±527.2)	3131(±355.5)
Birth Length	47.9(±2)	51.2(±4.3)	48.5(±2.2)
PI	3.0(±0.2)*	2.7(±0.3)	2.7(±0.2)
APGAR1	8.5(±0.5)	8.0(±2.0)	8.7(±0.6)
APGAR5	8.9(±0.4)	8.3(±1.5)	9.0(±0)
Males	2	2	1
Females	6	2	2

Table 9. Neonatal demographic information at birth. Values are expressed as mean(±SD). Weight (grams), Length (cm), *PI*, Ponderal index (g/cm^3). *, p<0.05 compared to Control.

CHAPTER 5 – DISCUSSION

The purpose of this study was to compare the effects of aerobic and circuit training throughout pregnancy on maternal, fetal, and neonatal health outcomes, with the focus of determining if cardiovascular benefits and overall health improvements are derived from the inclusion of strength exercises, rather than solely aerobic exercise, during pregnancy.

Maternal Measurements

We hypothesized that we would find improvements in the measurements of maternal gestational weight gain (GWG), body composition, and resting heart rate (RHR) in women throughout pregnancy with exercising groups experiencing similar improvements. We further hypothesized that exercising groups would experience greater improvements compared to controls. However, there was no difference in GWG between groups. This finding is similar to that reported by Ruchat et al,[91] in which excess GWG was prevented during an exercise and nutrition intervention, with controls gaining more weight than exercising women during the intervention period. Further, in accordance with our sample, women in the exercising groups gained weight similarly. Mottola et al[75] reported prevention of excess GWG in OW women, with the majority of the weight gained occurring prior to the start of the intervention. Conversely, Byrne et al[20] reported no differences in GWG in OB pregnant women between exercising and control groups. Each of these studies defined excess GWG as being greater than that recommended by Institute of Medicine (IOM) guidelines.[2] The lack of significant differences found in our sample could be influenced by the inclusion of all BMI classifications, rather than focusing on NW or OW/OB separately as in the aforementioned studies. Weight maintenance as a result of exercise training has also been reported in non-pregnant populations.[36]

Contrary to our hypothesis, only the aerobic group was able to closely maintain initial body fat percentage, experiencing less of a change in body fat % throughout gestation when compared to the circuit and control groups (Figure 3). Donnelly et al[36] found participants maintained body fat % compared to controls in response to aerobic exercise. To support the developing fetus, it is expected that women will gain weight during pregnancy. However, it can be assumed that participation in aerobic exercise training throughout pregnancy assists in maintaining a % body fat similar to pre-pregnancy value. This would further indicate that the increase experienced is solely due to the natural increase in weight to accommodate the growing fetus. Similarly, this adaptation also occurs in non-gravid women engaging in aerobic exercise training, resulting in either maintaining or decreasing body fat percentage.[36,41,42,86]

With regards to maternal RHR, there was no difference observed between groups, which had not been expected since individuals engaging in aerobic or resistance exercise training generally experience a decrease in RHR.[4,29,43] However, as pregnancy progresses, maternal RHR increases naturally to maintain BP and increase blood flow to the fetus.[4] Participants' exercise was tailored to maintain prescribed THR ranges, with increases in speed and resistance occurring throughout the study. These changes indicate that maternal HR during exercise was lower at the same relative intensity, which indicates training induced adaptations to the exercise protocol performed. Yet with no apparent change in RHR as a result of exercise training, there are possibly other factors involved in improved maternal cardiovascular function. These could include increased blood volume, increased SV, decreased vascular resistance, or decreased sympathetic tone, which would further impact maternal BP.[4]

In accordance with previous research, we did not expect to see a difference in maternal resting BP as a result of exercise training. No change in resting DBP occurred between the

groups similar previous findings.[4,67] However, we observed a difference in the change in resting SBP between groups (Figure 4). The control group experienced increased resting SBP throughout gestation as a result of increased sympathetic tone. Although a difference in SBP is not commonly seen throughout gestation, this adaptation is similar to non-pregnant women not engaging in exercise training.[4,103] Participants in the AT and CT groups experienced a decrease in resting SBP compared to controls. Although not commonly seen as a result of exercise training throughout gestation,[4,67] non-pregnant exercising women experience this same adaptation.[4,29,42,103] Decreased SBP following exercise training is a result of improved cardiovascular function due to decreased afterload (end-systolic volume), or the pressure the heart must overcome to pump blood throughout the periphery. Decreased afterload often indicates an increased stroke volume, resulting in a more efficient heart to supply blood to the periphery during exercise and at rest. Decreased afterload could also indicate that the arteries are more compliant (decreased vascular resistance) and able to be stretched to accommodate the amount of blood being pumped from the heart, or stroke volume (SV). Furthermore, decreased sympathetic tone can also influence arterial compliance, afterload, and SBP. Increased blood volume and decreased vascular resistance have been reported as naturally occurring during pregnancy.[4] Increased end-diastolic and stroke volumes as well as cardiac output (CO) have been reported previously as a result of exercise throughout pregnancy.[4,23] An increased end-diastolic volume is often coupled with a decreased end-systolic volume, or afterload, which decreases the amount of physiological strain on the heart at rest and during exercise. Generally, an increased SV would be coupled with a decreased HR as a result of exercise training. However, overall, this study did not find lower RHR in exercise groups. Lack of this adaptation to exercise training in the exercise groups could be attributed to participants not being fully rested prior to

measurements of RHR at each exercise session. The adaptation of a lower resting SBP and increase in SV could be the factors contributing most to improved cardiovascular health for women who exercise throughout pregnancy, despite the natural increase in RHR. Without knowing blood and plasma volume, SV, or CO in the present study sample, it is difficult to fully elucidate the full cardiovascular benefits acquired as a result of exercise during pregnancy.

Serum lipid levels were assessed to provide further insight regarding improved maternal cardiovascular health as is often observed as a result of exercise training in non-gravid populations.[54,56,57] All values for pre- and post-training measurements were similar to reference ranges of non-fasting serum lipid levels during pregnancy.[28,98] Pre-training serum lipid levels were similar between groups. Naturally, total cholesterol, HDL, and LDL levels increase as pregnancy progresses.[39,40,62,76,104] Because non-fasting samples do not accurately reflect serum triglyceride levels, these values were not assessed, and caution must be taken in interpreting calculated LDL values since they are further affected by the increased triglyceride values of non-fasting samples. At post-training, the CT group had increased values of total cholesterol (TC) relative to controls (Figure 5), and had trends of increased HDL cholesterol post-training compared to AT and control groups (Figure 6). Loprinzi et al[60] reported a positive association between increased HDL levels with increased physical activity throughout pregnancy. In the present sample, the increased value of TC in the CT group could possibly be explained by their increased HDL level. HDL cholesterol is a marker for improved cardiovascular health and well-being, with increased values being associated with increased health and cardioprotective benefits[4] and may also be associated with more normalized birth weights.[70] Although HDL levels increase due to aerobic exercise training,[4,54,55,56,57,60] we only found significant increases in the CT group and not the AT only exercisers. This discrepancy could possibly be explained by

individual pre-pregnancy activity levels or pre-pregnancy serum lipid levels, which were not analyzed in the present study. Additionally, the differences in serum lipid levels between groups could be due to the dietary choices of each participant. This relationship between maternal lipid levels, exercise, and diet is an area of future exploration.

Fetal Measurements

Similar to previous research,[24,27] we found no differences in fetal morphometrics between groups at 34 week measures. All values acquired for each measurement were within normal ranges for this stage in fetal development.[97] However, we found trends for AT fetuses to have larger HC and BPD relative to CT and control fetuses. This difference is most likely due to more male fetuses in the AT group[61] and possibly maternal and paternal genetics.[94] Another possibility for the observed differences is that this may represent a more mature development at the GA in the aerobic exposed babies similar to previous findings.[61,66] Humeral length of CT fetuses tended to be shorter compared to control fetuses. These differences are not functionally significant since all values are within normal ranges.[97] In addition to anthropometric measurements, no differences were observed in fetal anatomical heart measurements between exercising and control groups assessed at 34 weeks GA. These results further support that the fetus is not at adverse risk of stunted development as a result of exposure to varying types of exercise throughout pregnancy.[4,21,25,26,64,65,66,73,74,77,97]

No significant differences were observed in fetal LV physiological heart measures between groups. This is expected since the fetal heart is more RV dominant and usually has an approximately 28% increase in SV compared to the LV.[53] Similarly, our entire sample had a 25% increase in RV SV compared to the LV. This in mind, CT fetuses had significantly greater SV, with a trend towards greater EF, at 34 weeks GA relative to controls (Figure 7).

Additionally, there was a trend towards greater RV CO in fetuses exposed to aerobic and circuit exercise compared to controls (Figure 8). This increased SV and CO finding is similar to adults and children who exercise train.[83] All calculated measurements were within normal ranges observed in other healthy fetal populations.[72,96] These findings indicate that improved cardiovascular function and development occurs as a result of exposure to maternal exercise throughout pregnancy. The lack of significance in this measurement could be due to the smaller subset of fetuses compared in each group. This is the first study to assess fetal echocardiographic measurements associated with maternal physical activity. In adult populations it is well known that exercise training results in improved SV, EF, and subsequent CO, all contributing to improved cardiovascular health and function.[4,17,44,58,59,83,88] Several studies have investigated the influence of maternal exercise throughout pregnancy on fetal cardiovascular autonomic control. For example, fetuses of exercising women had improved cardiovascular autonomic control indicated by decreased heart rates and increased HRV, relative to those of non-exercisers.[64] Further analysis demonstrated a dose-response relationship, indicating that an increase in maternal exercise intensity and time spent participating in physical activity results in a greater fetal cardiovascular adaptation (i.e. decreased fetal HR and increased fetal HRV).[65] A recent study reported that both continuous (aerobic) and intermittent (circuit) exercise training throughout pregnancy are positively correlated to fetal cardiovascular adaptations.[66] Similar to our current findings, May et al[66] observed that intermittent exercise (i.e. strength exercises) throughout pregnancy may increase fetal heart adaptability compared to continuous exercise training (i.e. aerobic exercise) throughout pregnancy.[66] Furthermore, it has been hypothesized that fetal growth and development can be positively (i.e. exercise) or negatively (i.e. smoking) impacted by various maternal characteristics and behaviors, including exercise, which can have a

lasting effect on childhood growth and development.[11,12,84] These behaviors can increase (i.e. smoking) or decrease (i.e. exercise) the likelihood of the child developing chronic diseases such as obesity, hypertension, type 2 diabetes, metabolic syndrome, and coronary heart disease in childhood, and even into adulthood.[11,12,84]

Neonatal Measurements

In accordance with previous research, there were no differences observed in neonate weight between groups.[24,27,48,75,77,82,87,91,99] These results further support the finding that exercise during pregnancy is associated with normalized birth weights.[48,87] Normal birth weights are also associated with improved childhood health and protective from later developing chronic diseases, such as obesity, hypertension, type 2 diabetes, metabolic syndrome, and coronary heart disease.[11,12,84] Similar to previous studies, we found no differences in neonate 1 minute and 5 minute APGAR scores.[24,25,26,27,48,87] Additionally, ponderal index (PI) of neonates in the CT group was increased compared to AT and control groups, with several neonates of the CT group falling within the borderline high range (Figure 10).[50] There are several possible explanations for this observed difference. First, neonates with increased PIs may have increased muscle and decreased fat deposition, although percent fat at birth was not obtained to substantiate this claim. Second, it is possible that PI is not an accurate measure of neonate body composition or health just as BMI is not always an accurate measure of adult body composition and overall health status. All birth length and weight measures were within normal limits for all neonates, but the PI of those in the CT group was increased compared to the AT and control groups, suggesting that it may not accurately assess neonate body composition after being exposed to maternal exercise throughout pregnancy. For example, one study by Clapp[24] found decreased PI in offspring of exercising mothers compared to controls, while a second study by Clapp et al[25] found similar PIs

between neonates of exercising and control groups, and a third study by Clapp et al[26] found increased PIs. Similar to our current findings, this latter study by Clapp et al[26] found increased PIs in neonates when pregnant women decreased their exercise from 300 min/wk to 100 min/wk by 24 weeks GA then maintained this level until delivery. Similar to his previous findings, this difference was explained by the neonate's weight, length, and % body fat at birth. In each of his studies, Clapp reported that offspring had developed symmetrically despite the differences observed in weight, length, % body fat, and PI between groups.[24,25,26] To fully understand the significance of the differences in neonate PI observed between groups in the present study, it would be beneficial to obtain neonate % body fat in addition to weight, length, and PI.

Limitations

Although these findings are exciting, there are a few limitations. Selection of the sample was limited due to the geographic location of the study and by convenience of sample acquisition. The study was limited in its ability to recruit previously sedentary individuals. However, our demographic analysis found we had a diverse population of pregnant women participating in the study as far as ethnicity, education, and sedentary vs. trained prior to pregnancy. On an individual level, the study was limited by participant sickness, travel, and inclement weather. However, by utilizing two locations and flexible hours, we still maintained a 92% retention rate of participants.

Additionally, there are some considerations regarding study measures. Although one person calibrated all trainers, maternal measurements were assessed by multiple persons, which may have decreased the accuracy of the measures obtained. In the future, trainers taking measurements will be calibrated multiple times to ensure accuracy of measures. Calculation of GWG was limited by self-reported pre-pregnancy weight rather than actual weight measurement;

however, self-reported pre-pregnancy weight is commonly used in this type of research. Measurement of maternal RHR could also have been impacted based on whether or not the participant was truly in a rested state prior to taking the measurement. Future assessments should control the amount of time participants are seated prior to measurement of resting HR and BP. Lipid profile assessments were limited by being non-fasted, requiring LDL to be calculated from other measures rather than being precisely measured and analyzed. Although fetal ultrasounds were scheduled for the same time of day, we were limited based on fetal location and movement in utero at the time of the procedure.

Future Research

Future research in this area should include more previously sedentary and OW/OB women. This would help elucidate whether adaptations to exercise training experienced by participants were the result of exposure to exercise during pregnancy. Studies should also include a purely resistance training group in addition to the AT and CT groups, to determine if the inclusion of strength exercises is responsible for the present differences observed between the AT and CT groups, or if it is the CT protocol. If the latter, future research should compare different types of circuit training regimens throughout pregnancy to determine which, if any, provide the greatest health benefits. Since the maternal cardiovascular system changes during pregnancy, it would be beneficial to include other measurements of maternal cardiovascular adaptations as a result of exercise training, including blood plasma volume, blood hematocrit, stroke volume, and cardiac output. Additionally, fetal HR and HRV should be ascertained in the ultrasound at 34 weeks GA to further explain underlying autonomic cardiac control and function of the developing fetal heart. Future research should acquire neonate body fat % in addition to other anthropometric measurements to better understand observed differences between groups.

Conclusions

These results suggest that maternal aerobic training during pregnancy may have the greatest impact on maternal health and fetal health, which is further influenced by maternal circuit training. Results suggest that maternal body composition is maintained as a result of aerobic training during pregnancy and that maternal cardiovascular health may be improved via mechanisms aside from modulation of RHR. It is further suggested that fetal cardiovascular function and development is impacted by maternal exercise training during pregnancy, although the mechanisms underlying this effect are still unknown. Additionally, neonatal body composition may be impacted differently based on the type of exercise training completed during pregnancy. In conclusion, when following recommended exercise guidelines published by the American Congress of Obstetrics and Gynecology (ACOG), these results suggest that 1) different modes of physical activity decrease body fat gain and improve maternal heart health, 2) different types of exercise improve fetal heart function, and 3) different types of exercise do not adversely affect growth and may impact neonatal body composition. Therefore, women can and should participate in different types of exercise during pregnancy, receiving individual health benefits, extending to the health of their baby.

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APPENDIX: IRB Approval Letter

EAST CAROLINA UNIVERSITY
University & Medical Center Institutional Review Board Office
4N-70 Brody Medical Sciences Building· Mail Stop 682
600 Moye Boulevard · Greenville, NC 27834
Office **252-744-2914** · Fax **252-744-2284** · **www.ecu.edu/irb**

Notification of Initial Approval: Expedited

From:	Biomedical IRB
To:	Linda May
CC:	Carmen Moyer
Date:	5/10/2013
Re:	UMCIRB 12-002524 Enhanced Neonatal Health And Neonatal Cardiovascular Effects Developmentally

I am pleased to inform you that your Expedited Application was approved. Approval of the study and any consent form(s) is for the period of 5/9/2013 to 5/8/2014. The research study is eligible for review under expedited categories #2,#5, and #7. The Chairperson (or designee) deemed this study no more than minimal risk.

Changes to this approved research may not be initiated without UMCIRB review except when necessary to eliminate an apparent immediate hazard to the participant. All unanticipated problems involving risks to participants and others must be promptly reported to the UMCIRB. The investigator must submit a continuing review/closure application to the UMCIRB prior to the date of study expiration. The Investigator must adhere to all reporting requirements for this study.

The approval includes the following items:

Name	Description
Aerobic Home Exercise Sheet | History	Additional Items
Circuit Home Exercise Sheet | History	Additional Items
Exercise Session Log Sheets | History	Additional Items
HIPAA Form.docx | History	HIPAA Authorization
Informed consent- no more than minimal risk | History	Consent Forms
Maternal Measurements Form | History	Additional Items
Modified Balke Protocol.docx | History	Standardized/Non-Standardized Instruments/Measures

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[Modified Physical Activity Questionnaire](#) | [History](#)	Surveys and Questionnaires
[Photo Informed Consent](#) | [History](#)	Consent Forms
[Recruitment Criteria Card](#) | [History](#)	Recruitment Documents/Scripts
[Resistance Home Exercise Sheet](#) | [History](#)	Additional Items
[Sheffield FFQ.doc](#) | [History](#)	Surveys and Questionnaires
[Stretching Home Exercise Sheet](#) | [History](#)	Additional Items
[Thesis Proposal](#) | [History](#)	Study Protocol or Grant Application

The Chairperson (or designee) does not have a potential for conflict of interest on this study.

IRB00000705 East Carolina U IRB #1 (Biomedical) IORG0000418
IRB00003781 East Carolina U IRB #2 (Behavioral/SS) IORG0000418