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# Is Physical Activity During Late Pregnancy Related to Infant Body Composition at Birth?

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# IS PHYSICAL ACTIVITY DURING LATE PREGNANCY RELATED TO INFANT BODY COMPOSITION AT BIRTH?

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Associate Provost for Research and Graduate Education

I dedicate this thesis to my parents, Kim and Kristy, for I am forever grateful for their constant love, guidance, and support in pursuing my dreams. Thank you both for the endless opportunities and experiences that have made me who I am today. I also write this dedication to my three wonderful mentors-Dr. Tinius, Dr. Maples, and Dr. Esslinger. I truly appreciate the knowledge and wisdom you all have imparted on me that extends far beyond this paper. This journey would not have been possible if not for all of you, and I dedicate this milestone to you.

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CONTENTS

LIST OF FIGURES

LIST OF TABLES

IS PHYSICAL ACTIVITY DURING LATE PREGNANCY RELATED TO INFANT BODY COMPOSITION AT BIRTH?

Brenna Menke May 2020 97 pages

Directed by: Rachel Tinius, Jill Maples, and Keri Esslinger

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Exercise is typically regarded as having a positive impact on maternal and infant health. However, the relationship between maternal physical activity and infant body composition is unclear. The aim of this project was to determine how a physically active lifestyle during late pregnancy influences infant anthropometrics at birth. Pregnant women (34-39 weeks gestation) with low-risk pregnancies were given the Pregnancy Physical Activity Questionnaire (PPAQ) and an accelerometer to wear on their non-dominant wrist for seven consecutive days. Approximately 24-48 hours after delivery, infant body composition was assessed utilizing air displacement plethysmography at the patients' bedside. Fifty-five pregnant women participated (age: 30.8±4.5 years; pre-pregnancy BMI: 25.8±6.4 kg/m$^2$). There were no significant correlations between maternal physical activity levels (sedentary, light, moderate) assessed via accelerometry and PPAQ and infant adiposity (PEA POD), even after controlling for infant's gestational age, gestational weight gain, pre-pregnancy BMI, and parity. Further, when the most sedentary women and most active women were compared, there were no significant differences observed in infant body fat percentage (12.0±4.5 % vs.13.6±3.2 %, respectively; p=0.377). Secondary findings concerning infant body composition included: Infants born vaginally were heavier (3.6±0.4 g vs.

3.1±0.4 g; p=0.002) and tended to have a higher percentage of body fat (PEA POD) (14.01±4.3 % vs. 11.29±2.6 %; p=0.040) than those infants who were delivered by cesarean section (C/S). Infants born Large-for-Gestation Age (LGA) had a higher percentage of body fat (PEA POD) but this finding was not statistically significant (15.6±2.0% vs. 13.1±4.0% p=0.142). With regard to parity, infants second (or higher) in the birth order tended to have a higher percentage of body fat (PEA POD) (14.16±3.9% vs. 12.33±3.8%, p=0.088). Contrary to our hypothesis, there was not a significant correlation between late pregnancy physical activity and infant body fat percentage. Physical activity during late pregnancy does not appear to correlate to infant adiposity; suggesting physical activity during late pregnancy is safe and at least does not have a detrimental impact on infant anthropometrics.

*Keywords*: Pregnancy; neonatal adiposity; air-displacement plethysmography; exercise

## Introduction

Pregnancy is a critical time point for health-related changes and decisions. In addition to sustaining and growing a fetus, a woman undergoes many other physiological changes that affect both the mind and body during pregnancy and for years after. Many women experience a new or renewed sense of motivation for making lifestyle changes as suddenly their health-related decisions impact their unborn child (McCarthy et al., 2016; Sui, 2013). Therefore, a thorough understanding of infant outcomes that can be improved through exercise is warranted.

Obstetricians and other women's health care providers are encouraging healthy women to exercise during pregnancy as there is growing evidence to support the association between safe physical activity during pregnancy and maternal and infant health benefits (Moyer et al., 2016b; Mudd et al., 2013; Prather et al., 2012). These potential benefits for infants include increased gestational age at delivery, higher Apgar scores, decreased risk for small-for-gestational age(SGA), decreased risk for large-for-gestational age((LGA)/macrosomia), lower percentage of fat mass, decreased risk of future chronic disease development, and a potential for improved neurodevelopment (Moyer et al., 2016b). Despite all of these benefits, only 15 percent of pregnant women meet the current physical activity guidelines recommended by the American College of Sports Medicine (ACSM) and the American College of Obstetrics and Gynecology (ACOG) of 150 minutes of moderate-intensity activity per week (Evenson et al., 2014). A failure to meet these recommendations has been linked to maternal weight gain, chronic disease, morbidity, and mortality (ACOG Committee on Obstetric Practice, 2020) and during pregnancy, can have downstream consequences for the infant (Fazzi et al., 2017).

Birth weight and length are traditional indicators of a healthy intrauterine growth environment (Clapp et al., 2000). Traditionally, “chunky” or large babies have been identified as well-fed, healthy babies (Ong, 2006). However, there is growing concern over the increase in birth weights of babies born small for gestational age (SGA), large for gestational age (LGA), and macrosomic, specifically, from mothers who are obese. A macrosomic infant is one whose birth weight is above 4,000 grams regardless of birth length, occurring in about nine percent of births (Owe et al., 2009). Increases in birth weight above four kg can likely indicate corresponding increases in adiposity later in life (Zhang et al., 2008). Presence of adiposity at birth through two years is recognized as a predictor for childhood obesity and for developing metabolic syndrome or other non-communicable diseases as adults (Barbour et al., 2016; McCarthy et al., 2016). On the other end of the spectrum, a SGA infant has a birth weight below 2,500 g and is often associated with intrauterine growth restriction (Sayers et al., 2017). During the first six months of life, the majority of SGA infants experience early catch-up growth followed by a normal pattern of growth. However, the catch-up growth seems to be associated with fat mass rather than lean mass and can place SGA children at higher risk for developing cardiovascular disease and other diseases associated with metabolic syndrome (Cho & Suh, 2016).

Several studies have found that exercise during pregnancy is linked with lower infant birth weights (Bisson et al., 2017; Pastorino et al., 2018) and does not inhibit healthy growth of the fetus (i.e., lead to SGA infants or intrauterine growth restriction (IUGR)) (Clapp et al., 1998; Mudd et al., 2013; Pivarnik, 1998). However, birth weight alone cannot adequately estimate adiposity. In adults, methods that measure body fat versus lean mass are better predictors of health outcomes than weight or BMI alone (Lee et al., 2018).

While many studies have investigated the role of exercise in infant birth weight, limited research exists on maternal exercise during pregnancy and infant body composition. Body composition, specifically fat mass relative to fat-free mass, at birth is a better determinant of adiposity than birth weight alone (Hopkins et al., 2010). Clapp & Capeless found that women who were previously active and remained active throughout pregnancy, by participating in moderate-vigorous physical activities(MVPA) three days per week, gave birth to infants with less fat mass (assessed via skinfolds) than those who were not active (Clapp & Capeless, 1990). A similar decrease in infant fat mass (assessed via PEA POD) was found in the *Healthy Start Study* (2014) with increasing levels of MVPA during late-pregnancy (Harrod et al., 2014). However, a recent systematic review of exercise-only randomized control trials reported an inverse association between MVPA during pregnancy and reducing births on the extreme ends of birth weight (i.e., SGA & Macrosomia) while no association was found with infant body composition (i.e., fat mass, fat-free mass, percent fat mass, BMI) (Davenport et al., 2018). There is some evidence that the intensity (Pivarnik,

1998) and timing (Pastorino et al., 2018) of physical activity may be modifying factors. Findings across the literature are inconsistent and there is a need for more reliable and valid methodologies.

Skinfolds are a traditional method used for measuring body composition in infants. While skinfolds are the most common anthropometric measurement tool because of the ease of use and low cost, there is limited precision and accuracy in infants (Barbour et al., 2016; Cauble et al., 2017; Demerath & Fields, 2014). Air-displacement plethysmography (ADP) is now regarded as the gold standard method for measuring infant body composition (Barbour et al., 2016; McCarthy et al., 2016). Infant ADP (PEA POD) has increased in popularity in clinical research as it is simple to use, fast, possesses no risk to an infant, and doesn't require an infant to lie still. However, it is expensive, and many medical centers do not have access to this technology. Because of this, there is limited research investigating physical activity during pregnancy and how it relates to infant body composition utilizing the PEA POD. The impact of physical activity during late pregnancy on infant body composition is still unclear. Because infant ADP is the new gold standard for assessing infant body composition, more research is needed to determine the role of physical activity during pregnancy on infant body composition utilizing this methodology.

***Therefore, the aim of this project was to examine the association between physical activity during late pregnancy (34-39 weeks gestation) and infant anthropometric outcomes utilizing the new gold standard***

***method for body composition (PEA POD).* In order to accomplish this goal, physical activity was measured subjectively and objectively during late pregnancy and the infant's body composition was measured through the PEA POD within 48 hours of birth.** *The hypothesis for this study is that maternal physical activity levels during pregnancy will be negatively correlated with infant body composition at birth (i.e. more active moms will deliver leaner babies).*

## Literature Review

Physical activity (PA) is a core component of a healthy lifestyle. It covers a range of activities from incidental movement (including walking to get places and activities of daily living) to leisure-time physical activity (LTPA) (such as sports and exercise) that all range from light to moderate and/or vigorous intensities (MVPA). Physical activity has a tremendous amount of benefits for nearly any population including children, adolescents, adults, pregnant women, older adults and adults with chronic diseases or disabilities (i.e., as long as they are able). In fact, physical activity may be the single best preventative medication that exists (Warburton et al., 2006). Across all life stages, PA improves cardiorespiratory fitness, reduces the risk of obesity and associated comorbidities, and contributes to overall longevity (American College of Sports Medicine et al., 2018). Similar to the general population, exercise during pregnancy is extremely beneficial for mothers and babies throughout pregnancy and has lasting benefits into the postpartum period (ACOG Committee on Obstetric Practice, 2020).

During pregnancy, there are many physiological and anatomical changes that occur to provide a healthy environment for the growing fetus. However, situations exist where normal physiologic changes associated with pregnancy can be exacerbated and become problematic for the mother or baby. For example, all women become more insulin resistant during pregnancy as a mechanism to spare glucose for the fetus; however, some women, specifically those with pre-existing glucose control issues or weight issues, may experience gestational diabetes as a result. Many of these changes have an immediate impact on maternal and fetal health while others can have a long-term impact if left unmonitored or untreated. Fortunately, evidence suggests that exercise during pregnancy can improve maternal outcomes and provides a variety of benefits to the mother throughout pregnancy, during labor, and through the postpartum period.

### The Role of Physical Activity During Pregnancy for Improving Common Maternal Outcomes

A common physiological response to pregnancy is a slight increase in maternal insulin resistance and a decrease in glucose tolerance in order to spare glucose for the growing baby (King, 2000). However, for some women this natural shift in insulin resistance leads to the development of gestational diabetes mellitus (GDM). GDM is the onset of hyperglycemia first diagnoses during pregnancy. Current evidence suggests that exercise can help prevent the development of GDM and improve glucose control throughout pregnancy (Mudd et al., 2013). Preventing and controlling GDM is important for infant health as there is an increased risk for developing excessive birth weight, adiposity at birth, preterm labor, stillbirth, breathing difficulties, obesity and other metabolic disorders in adulthood (Mudd et al., 2013).

Weight gain is a normal and expected part of pregnancy. However, recommended weight gain is dependent upon pre-pregnancy body mass index (i.e. overweight and obese women should gain less weight than normal weight or underweight women) (Rasmussen & Yaktine, 2009). One of the main goals of prenatal care is for providers to evaluate and monitor maternal weight gain throughout pregnancy. It is critical to monitor progress towards gestational weight gain (GWG) goals and provide individualized counseling if necessary as nearly 50 percent of women today exceed their GWG goals (Deputy et al., 2015). Maternal GWG and postpartum weight retention are directly related. Weight retention in the postpartum period has potential to create a cascading effect leading to excess GWG in subsequent pregnancies and future obesity (Mudd et al., 2013). If excessive GWG is left unmonitored, it can contribute to maternal GDM risk, preeclampsia, preterm labor, postpartum weight retention and lead to birth complications such as intrauterine growth restriction and macrosomia (Streuling et al., 2011). Evidence suggests physical activity during pregnancy may play a role in GWG management strategies (Streuling et al., 2011). Specifically, a review by Mudd et al. (2013) suggests that a lifestyle approach is necessary; exercise and nutrition must be prescribed in combination in order to effectively prevent excessive GWG (Mudd et al., 2013).

Gestational hypertension disorders are on the rise and are one of the leading causes of maternal morbidity and mortality (Lo et al., 2013). Preeclampsia is a gestational hypertensive disorder that develops in the beginning of pregnancy and is diagnosed after 20 weeks gestation. It occurs in about 10 percent of pregnancies and can cause issues throughout pregnancy including maternal multiorgan failure, preterm birth, intrauterine growth restriction, and increased perinatal mortality (Mudd et al., 2013). A recent review and meta-analysis concluded that participating in aerobic activities for 30-60 minutes most days of the week during pregnancy can help reduce the risk and incidence of gestational hypertension disorders as well as reduce the risk of adverse birth outcomes associated with preeclampsia (Magro-Malosso et al., 2017).

Physical activity during pregnancy has also shown to provide some benefit for other birth outcomes such as increased gestational age, improve labor and delivery, and reduce the rate of operative deliveries, (ACOG Committee on Obstetric Practice, 2020; Mudd et al., 2013). While some studies suggest women who exercise are more likely to deliver closer to their due date, women of low-income minority groups and women with GDM or gestational hypertensive disorders, who participated in LTPA throughout pregnancy, significantly reduced their risk for preterm birth (Moyer et al., 2016). Clinically, it is important for an infant to make it closer to term as those children need less medical assistance at birth than close to term or preterm infants (Moyer et al., 2016). Specifically, term infants have more favorable APGAR scores, improved temperature control, improved respiratory response, and an appropriate weight for gestational age (Wang et al., 2004). In a normal pregnancy, the labor process of natural births has been found to be shorter in women who exercised compared to those who were sedentary (Poyatos-León et al., 2015). A recent study found that the first stage and total time in labor was significantly shorter for women who participated in aerobic exercise three days a week throughout pregnancy (Barakat et al., 2018). Additionally, there is some evidence to suggest that exercise during pregnancy can reduce the risk of operative deliveries (Barakat et al., 2012). Specifically, exercise during the second and third trimesters can significantly reduce the risk of a cesarean delivery (Poyatos-León et al., 2015). Cesarean Section deliveries pose maternal risks which include infection, postpartum hemorrhage, surgical injury, and increased risk during future pregnancies; infant risks include both short-term breathing difficulties and lack of temperature control as well as long term risks such as obesity and asthma (Sandall et al., 2018).

Maternal PA benefits also extend into the postpartum period with shorter recovery times and reduced risk of postpartum depression (ACOG Committee on Obstetric Practice, 2020). There is evidence to suggest that previously sedentary women who are active throughout pregnancy can improve their postpartum recovery time (Price et al., 2012). Additionally, regardless of delivery method, active women have significantly shorter recovery times after birth than those who were sedentary throughout pregnancy (Price et al., 2012). A recent review found that the risk of developing postpartum depression was significantly reduced in women who exercised during pregnancy (Nakamura et al., 2019). Despite all of these well-established benefits, it is still unclear what amount and intensity of physical activity has the greatest impact on outcomes. Further, studies all look at physical activities in varying capacities, making it difficult to generalize. The intensity, frequency, duration, type of PA, and/or trimester of pregnancy may all modulate the relationships between PA and outcomes (Nakamura et al., 2019).

The Role of PA for Improving Infant Outcomes

In addition to improvements in maternal health, physical activity during pregnancy has been shown to have benefits for the infant as well including healthy growth and improved cognition and intelligence (Clapp et al., 1999; Moyer et al., 2016). Birth outcomes are commonly measured to identify the overall health of a newborn. Infant anthropometrics are the majority of birth outcomes measured which include birth weight and classifications (i.e., large for gestational age (macrosomia) and small for gestational age), birth length, circumferences, weight-to-height ratios (i.e., Ponderal Index (PI) and Body Mass Index (BMI)) and body composition (fat mass and fat-free mass). All articles and the infant outcomes analyzed are listed by study in Table 1.

***Birth Weight*.** Birth weight is a traditional infant anthropometric measurement and is used as an indicator of a healthy intrauterine growth environment (Clapp et al., 2000). It is the most frequently reported birth outcome with classifications based on gestational age as a percentile and the evidence of how physical activity impacts it are still unclear. Most of the literature points to a lower birth weight (i.e., 150-400 g less) in physically active mothers, without increasing the risk for low birth weight (Bisson et al., 2017; Pastorino et al., 2018). However, other researchers have found no differences and some have even found an increase in birth weights (within the normal range) based on the intensity of the exercise (Bisson et al., 2017; Clapp et al., 2000). A shift in the mean birth weight within the healthy range (i.e., 2500 - 4000 g) may be irrelevant to clinicians as the concern is primarily on the extreme ends of weight (i.e., SGA & LGA) where an increase in risk of complications occurs (Owe et al., 2009). Overall, the impact of physical activity on birth weight is unclear; it appears that PA does not have an influence on BW, but this relationship appears to be complicated and dependent on the intensity of activity performed.

***Large-for-gestational age.*** Large-for-gestational age (LGA) is defined as a birth weight greater than the 90$^{th}$ percentile for age, above 4,000 g (Xu et al., 2010). Further, macrosomia refers to excessive intrauterine growth beyond a certain threshold regardless of gestational age commonly defined a birth weights above 4,500 g (Owe et al., 2009). Evidence suggests that prenatal exercise can decrease the risk of macrosomia by 39% without increasing the risk for SGA, low birth weight, or intrauterine growth restriction (Davenport et al., 2018). One randomized controlled clinical trial found a decrease in the rate of macrosomic infants in the intervention group compared to the control group where mothers exercised three days/week in the second and third trimester (Barakat et al., 2016). Another study found that exercising for three days a week during the second trimester significantly decreased incidence of macrosomia while participating in physical activity before pregnancy had no effect (Owe et al., 2009). In a recent meta-analysis, vigorous physical activity had the biggest effect on macrosomia across all trimesters of pregnancy (four percent reduction of risk) while moderate physical activity only had a significant impact during late pregnancy (Pastorino et al., 2018). While it is not entirely clear how much physical activity is enough to reduce the risk of delivering an infant with a high birth weight, intensity of the exercise and the time point of pregnancy may be key factors driving the relationship between PA and LGA.

***Small-for-gestational age*.** Being born with a low birth weight can have lasting impacts on development and survival (Belbasis et al., 2016). A significant low birth weight is < 2500 g and termed small-for-gestational age (SGA) (Xu et al., 2010). When assessing birth weight, multiple studies found no differences in the risk of delivering a baby with SGA and participating in leisure time physical activity during pregnancy (Davenport et al., 2018). Findings from a recent meta-analysis also suggest that MVPA during late pregnancy can lower birth weights without increasing the risk for SGA (Pastorino et al., 2018). In an observational study by Harrod et al., the mothers who had the highest amounts of total energy expenditure compared to those with the lowest were three times more likely to deliver an infant with SGA (Harrod et al., 2014). However, the difference may be attributed to the reductions in fat-mass and not in reductions of lean mass (Harrod et al., 2014). In a recent study with overweight and obese women enrolled in a trial to promote lifestyle changes, researchers found those who remained sedentary had a significantly higher chance of delivering a SGA infant than those who participated and met LTPA guidelines set by ACOG of 150 minutes of moderate-intensity PA per week (ACOG Committee on Obstetric Practice, 2020; Trak-Fellermeier et al., 2019).

***Ponderal Index.*** Ponderal index (PI) is a weight-to-length ratio, similar to a body mass index for an adult, that can be calculated with data from birth records as [weight/length$^3$ (kg/m$^3$)]. PI can be used as an indicator of fetal growth status, specifically for infants at the extreme ends of the weight distribution where infant morbidity is commonly found (Ong, 2006). Additionally, PI can be used with significant increases in birth weight as an indicator of adiposity at birth. Due to ease of access, these outcomes are commonly reported with birth weight and length across studies (Table 1). With studies reporting mixed birth weight results and no significant differences in birth length with maternal PA during pregnancy (Davenport et al., 2018), the PI findings have also varied. A recent cohort study evaluated pre-pregnancy and early pregnancy (i.e., 15 weeks) LTPA walking and yoga activities and identified the infants born to mothers who participated in yoga and walking had a significantly smaller PI than infants of sedentary mothers (Badon et al., 2018). Similarly, two randomized clinical trials looking at moderate intensity PA throughout pregnancy found significantly smaller PI in infants of the intervention groups (Clapp & Capeless, 1990; Hopkins et al., 2010). While there is a trend of a lower PI with increasing maternal LTPA during late pregnancy (Pastorino et al., 2018), it may not be sensitive enough to detect infant body composition changes at birth.

**Circumferences.** Circumference measurements in an infant at birth are also considered as a means of assessing overall health and development in utero (Johnson & Engstrom, 2002). Head circumferences are taken at birth to identify overall brain development (Clapp et al., 2000) and can be an indicator for intrauterine growth restriction, in addition to the fetus's body size (Clapp et al., 2000). Abdominal circumferences are taken to help determine intra-abdominal fat-mass distribution and estimate adiposity (Harrod et al., 2014). While most of the studies aimed to observe or implement LTPA during pregnancy have shown no significant differences in head and abdominal circumferences, there are a few studies that have conflicting findings for head circumference (Table 1). Two studies found a significant increase in head circumference on infants born to exercising mothers compared to the control mothers (Badon et al., 2016; Clark et al., 2019). In contrast, three cohort studies identified a slight decrease in head circumference in infants born to active women compared to those born to sedentary women but was within the normal range for healthy growth (Joshi et al., 2005; Juhl et al., 2010; Rao et al., 2003). Although evidence is conflicting, these studies, taken together, do suggest that exercise does not negatively affect healthy development in utero.

**Body fat.** Birth weight is the traditional indicator of a healthy intrauterine growth environment (Clapp et al., 2000). However, weight alone cannot adequately estimate fat mass relative to fat-free mass in infants. Another term for excess fat mass is adiposity. The rate of adiposity at birth is increasing among infants born to obese mothers (Starling et al., 2015). Presence of adiposity at birth and throughout the first two years of life is recognized as an important predictor of childhood obesity and risk for developing chronic metabolic diseases (Barbour et al., 2016; McCarthy et al., 2016). Infant body composition can be evaluated through skin folds, dual-energy X-ray absorptiometry (DXA), or air-displacement plethysmography (PEA POD) and is commonly assessed between 72 hours and two weeks of birth.

***Skinfolds*****.** Although there is limited reproducibility and precision of skin folds (SF) in infants, researchers continue to use the measurement as it is available, cost effective, time efficient, portable, and safe (Barbour et al., 2016). Skinfold outcomes reported are conflicting as collectively, observational studies do not identify a significant association or difference in skinfolds between active and inactive women, whereas findings from clinical trials are mixed (Table 1). For observational studies, differences may not be observed with the skinfold outcomes as the physical activity assessment techniques and quantities of physical activity varies greatly in addition to the number of skinfold sites measured and equations used (Bisson et al., 2015; Joshi et al., 2005; Rao et al., 2003; van Poppel et al., 2019). There is currently no consistent and well-established methodology for assessing and calculating infant body composition via skinfolds. In a recent clinical trial, there were no differences observed in the estimated infant fat mass by skinfolds between the physical activity intervention group and the control group (Garnæs et al., 2017). This finding is in contrast to the various studies completed by Clapp who observed significant decreases in infant skinfold sums and fat mass estimates (Clapp et al., 1998, 2002; Clapp & Capeless, 1990) among women who were active during pregnancy. In addition to the Clapp studies, two recent RCT studies observed similar decreases in skinfold sums and fat mass estimates of infants born to active mothers compared to inactive mothers (Trak-Fellermeier et al., 2019; van Poppel et al., 2019). However, the PEARLS study (2019) only identified the decrease of fat mass via skinfolds in males as opposed to higher estimates of fat mass via skinfolds in females regardless of the mother's PA participation (Trak-Fellermeier et al., 2019).

***DXA*.** Dual-energy X-ray absorptiometry (DXA) is a four compartment method which is viewed as the most accurate measure of body composition in infants (Bisson et al., 2017). However, there are limitations to the DXA scan used in research such as cost, access, ease of use, require the infant to remain still, and marginal safety concerns (Barbour et al., 2016). A DXA scan can be used to determine fat mass, fat-free mass, body fat percentage, and bone mineral density in infants at two weeks of age. There were two studies, one RCT and one cohort, that utilized DXA to measure infant body composition outcomes. In the cohort study utilizing an accelerometer to collect PA, mothers who participated in vigorous PA at 17 weeks gave birth to infants with significantly less fat mass and a lower percent fat compared to the infants whose mothers only participated in light to moderate LTPA (Bisson et al., 2017). Although researchers did not observe decreases in infant fat mass with MPA at 17 and 36 weeks, MPA participation at 36 weeks was significantly associated with increases of fat-free mass (i.e., lean mass) when engaged in at least 90 minutes of MPA activity per week (Bisson et al., 2017). There was a similar finding in the RCT of a stationary bicycling program of moderate intensity. While no differences in infant fat mass were observed, there was an increase in fat-free mass in the infants of mothers who were in the intervention group (Hopkins et al., 2010).

***Infant ADP*.** Infant air displacement plethysmography (PEA POD) (COSMED Inc, Concord, CA, USA) has become a popular alternative to measure infant body composition. The PEA POD uses air displacement plethysmography and a two-compartment model to measure body weight and volume to determine fat mass, fat-free mass, and body fat percentage based on known densities of fat (Barbour et al., 2016). Results have been conflicting using a PEA POD (Table 1). In two recent cohort studies that gathered PA by recall, differences in infant fat mass were observed between active (i.e., LTPA participation on most days of the week) and inactive mothers; however, the differences were observed at varying intensities (Dahly et al., 2018; Mudd et al., 2019). In the CORK cohort

(2018), mothers who participated in frequent MPA during early pregnancy tended to have infants with lower fat mass than women who occasionally participated in MPA or those who were inactive (Dahly et al., 2018). In contrast, a recent study by Mudd et al. (2019) found that vigorous PA during late pregnancy was associated with lower infant fat mass while moderate PA during late pregnancy was not associated with infant fat mass, which is consistent with what other studies have found (Bisson et al., 2017; Mudd et al., 2019; Pastorino et al., 2018). Even though a few studies have found decreases in fat mass with increases in PA duration and/or with higher intensities during pregnancy, a recent review suggests PA may not have an impact on infant fat mass (Davenport et al., 2018). In a study with mothers who were overweight or obese determined by pre-pregnancy BMI, researchers found an association between infant fat mass and maternal BMI but there was not an association with maternal leisure time PA (McCarthy et al., 2016). Researchers in The Healthy Start study (2014) observed a significant decrease in infant fat mass and subsequent increase in fat-free mass in infants of women who participated in MVPA on most days of the week plus increased their total energy expenditure in late pregnancy (Harrod et al., 2014). The findings from this study are significant as many women transition into more sedentary activities during the third trimester (Fazzi et al., 2017). Further, total energy expenditure may be a key factor contributing to lowering adiposity in the infant.

| Title, Author(s) & country | Year | Trimester (weeks) | Physical Activity Assessment | | | Infant Anthropometrics | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ✓** denotes significant difference | | | Self-report; Accelerometer | Intervention | Intensity | Birth Weight | Birth Length | SGA | LGA | Ponderal Index | Circumferences | % Body Fat | BF Assessment |
| Maternal Leisure Time PA..Badon et al, U.S. | 2016 | 15 wks | X | | light to moderate | ✓ | ✓ | | | ✓ | ✓** | | |
| Associations of Maternal Light/Moderate..Badon et al, U.S. | 2018 | 15 wks | X | | light to moderate | ✓** | ✓ | | | ✓** | ✓ | | |
| Resistance Exercise Training During Pregnancy..Barakat, Lucia, and Ruiz, Spain | 2009 | 12-39 wks | | X | light to moderate | ✓ | ✓ | ✓ | ✓ | | ✓ | | |
| 12-week Exercise Program..Bisson et al, Canada | 2015 | 14, 28, 36 wks | X | X | moderate | ✓ | ✓ | ✓ | ✓ | | ✓ | ✓ | SF |
| Influence of maternal PA..Bisson et al, Canada | 2017 | 17 wks; 36 wks | X | | MVPA | ✓** | | ✓ | ✓ | | | ✓** | DXA |
| Neonatal Morphometrics..Clapp & Capeless, U.S. | 1990 | Preconception-40 wks | | X | moderate | ✓** | ✓ | | | ✓** | ✓ | ✓** | SF |
| The one-year morphometric..Clapp et al, U.S. | 1998 | Follow-up of previous study @ 1 yr | | X | moderate | ✓** | ✓ | | | | ✓ | ✓** | SF |
| Beginning regular exercise..Clapp et al, U.S. | 2000 | Preconception testing; program 8-40 wks | | X | moderate | ✓** | ✓** | | | ✓ | ✓ | ✓ | SF |
| Continuing regular exercise..Clapp et al., U.S. | 2002 | Preconception testing; program 8-40 weeks | | X | moderate | ✓** | ✓ | | | | | ✓** | SF |
| Influence of aerobic exercise..Clark et al, U.S. | 2019 | 16 wks-36 wks | X | X | moderate | ✓ | ✓ | | | ✓ | ✓** | | |

**Table 1. Literature Chart**

| Title, Author(s) & country | Year | Trimester (weeks) | Physical Activity Assessment | | | Infant Anthropometrics | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ✓ ** denotes significant difference | | | Self-report; Accelerometer | Intervention | Intensity | Birth Weight | Birth Length | SGA | LGA | Ponderal Index | Circumferences | % Body Fat | BF Assessment |
| Associations between maternal (CORK)..Dahly et al, Ireland | 2018 | 15 wks &/or 20 wks | X | | light to moderate | ✓ | ✓ | | | | | ✓ ** | PEAPOD |
| A RCT of exercise..da Silva et al., Brazil | 2017 | 16-36 wks | | X | moderate | ✓ | ✓ | ✓ | ✓ | | ✓ | | |
| Effect of supervised exercise..Garnaes et al, Norway | 2017 | 12-40 wks | | X | moderate | ✓ | ✓ | | | | ✓ | ✓ | SF |
| The Healthy Start Study..Harrod et al, U.S. | 2014 | 17 wks, 27 wks, late pregnancy (birth) | X | | light to moderate | ✓ | ✓ | ✓ ** | ✓ | | ✓ | ✓ ** | PEAPOD |
| Exercise Training in Pregnancy…Hopkins et al, New Zealand | 2010 | 20 wks - delivery | | X | moderate | ✓ ** | ✓ | | | ✓ ** | ✓ | ✓ | DXA |
| Increasing maternal parity..Joshi et al, India | 2005 | 18 wks, 28 wks | X | | light to moderate | ✓ ** | ✓ | | | | ✓ ** | ✓ | SF |
| Physical exercise during pregnancy..Juhl et al, Denmark | 2010 | 16 wks, 31 wks | X | | light to moderate | ✓ | ✓ | ✓ | ✓ ** | ✓ | ✓ ** | | |
| Parental PA..McCarthy et al., Ireland | 2016 | 15 wks | X | | light to moderate | | | | | | | ✓ | PEAPOD |
| Relations among maternal PA..Mudd et al, U.S. | 2019 | Recalled PA @ 4 yr Postpartum | X | | MVPA | ✓ | ✓ | | | | | ✓ ** | PEAPOD |
| Do changing levels of maternal exercise..Norris et al, Ireland | 2017 | up to 15 wks & 20 wks | X | | light to vigorous | | | | ✓ ** | | | ✓ ** | PEAPOD |
| Association between regular exercise..Owe et al., Norway | 2009 | 17 wks & 30 wks | X | | light to moderate | ✓ | | ✓ | ✓ ** | | | | |

**Table 1.** (Continued)

| Title, Author(s) & country | Year | Trimester (weeks) | Physical Activity Assessment | | | Infant Anthropometrics | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ✓** denotes significant difference | | | Self-report; Accelerometer | Intervention | Intensity | Birth Weight | Birth Length | SGA | LGA | Ponderal Index | Circumferences | % Body Fat | BF Assessment |
| Effects of PA..Przybyłowicz K., Przybyłowicz M., Grzybiak M., & Janiszewska K., Poland | 2014 | Postpartum Surveys | X | | light to moderate | ✓ | ✓ | | | ✓ | | | |
| Maternal activity in relation..Rao et al, India | 2003 | 18 wks & 28 wks | X | | light to moderate | ✓** | ✓ | | | | ✓** | ✓ | SF |
| Effects of antenatal exercise…Seneviratne et al, New Zealand | 2015 | 20-36 wks | | X | moderate | ✓ | ✓ | ✓ | ✓ | ✓ | | | |
| Nullparity is associated…Seneviratne et al, New Zealand, RCT | 2017 | 19-36 weeks | X | X | moderate | ✓** | | | | ✓ | | ✓ | DXA |
| Maternal Inflammation..Tinius, Cahill, Strand, & Cade, U.S. | 2016 | 32-37 wks | X | | light to vigorous | ✓ | ✓ | | | | ✓ | ✓ | PEAPOD |
| PEARLS..Trak-Fellermeier et al, Puerto Rico | 2019 | Baseline (<16 wks), (24-27 wks), (35-36 wks) | | X | light to vigorous | ✓ | ✓ | ✓** | ✓ | ✓ | ✓ | ✓** | SF |
| DALI trial..van Poppel et al, Netherlands | 2019 | <20 wks-37 wks | X | X | light to vigorous | ✓ | ✓ | | | | ✓ | ✓** | SF |
| The Influence of Objectively..Watson et al, South Africa | 2018 | 14-18 wks; 29-33 wks | X | | light to vigorous | ✓ | ✓ | | | ✓ | ✓ | | |
| Resistance Training During Preg…White, Pivarnik & Pfeiffer, U.S. | 2014 | Postpartum Surveys | X | | light to vigorous | ✓ | ✓** | | | | | | |

**Table 1.** (Continued)

*Physical Activity Impacts Over a Lifetime*

Understanding how exercise during pregnancy impacts infant outcomes at birth could predict the health of a child in the future (Davenport et al., 2018). Although birth weight is a traditional marker for a healthy intrauterine growth environment (Clapp et al., 2000), body composition may be a more sensitive marker for health later in life as some evidence points to lower body composition during childhood (Mudd et al., 2019) and a lower risk of obesity during childhood (Kong et al., 2016; Mudd et al., 2015). Specifically, Clapp found that children of mothers who exercised during pregnancy weighed less and had less body fat at birth and at age 5 than those infants of the mothers who discontinued exercise during pregnancy (Clapp, 1996). Recently, Mudd et al. found that any amount of vigorous PA during late pregnancy was associated with a lower infant fat mass at birth and at four years old (Mudd et al., 2019); moderate PA during any trimester was not associated with fat mass at birth or at four years (Mudd et al., 2019). Identifying maternal PA as a modifying factor of infant adiposity at birth may be crucial for preventing childhood obesity and reducing the risk for developing metabolic diseases in adulthood (Belbasis et al., 2016; Chandler-Laney et al., 2013).

*Summary of the Role of PA on Neonatal Anthropometrics*

Existing evidence on the role of physical activity during pregnancy on infant outcomes, specifically neonatal anthropometrics, is unclear and oftentimes conflicting. The conflicting results may be due to the lack of high-quality methodologies and inconsistencies in physical activity assessment, the time point physical activity during pregnancy is studied, and the frequency, intensity, time, and type of exercise performed.

The Role of Varying Exercise Parameters on Infant Outcomes

**Physical Activity Assessment.** For observational studies, many utilize a validated, self-report survey called the Pregnancy Physical Activity Questionnaire (PPAQ) (Chasan-Taber et al., 2004). Utilizing this questionnaire, researchers are able to identify the time women spend each day in five different activity areas-household/caregiving, occupational, sports/exercise, transportation, and in-activity to quantify their LTPA. Self-reported time spent in each activity is computed to MET·minutes and the average MET·hours per week are classified by type of activity and MET·hours per week for each intensity level. This questionnaire is considered the most feasible option for obtaining physical activity data for a large cohort (Owe et al., 2009) and it has been validated and widely used for pregnancy research. Chasan-Taber validated the PPAQ in 2004, and the PPAQ results had modest correlations with physical activity data collected through an accelerometer worn during pregnancy (Chasan-Taber et al., 2004). The strength of the correlation varied based on the cut points and activity level. The PPAQ has become widely accepted for use during pregnancy as it has been validated, translated to many different languages, and involves activities specifically relevant to women of child-bearing age. While PA during pregnancy research relies heavily on objective and subjective measures of PA (i.e., PPAQ), objective measurements are more accurate than even the most well-validated subjective assessments (Brett et al., 2015; Sattler et al., 2018).

Physical activity can be objectively measured in many different ways using a variety of fitness trackers and pedometers. However, the gold standard for assessing physical activity is using an accelerometer placed on the hip or the non-dominant wrist, commonly worn for an average of four to seven days. A recent study found that seven consecutive days of wrist-worn accelerometer wear time is needed to ensure compliance and gather reliable and accurate MVPA activity in pregnant women (da Silva et al., 2019). The percentage of time the wearer spends sedentary and participating in a range of activity levels (light, moderate, and vigorous) can be determined through step counts. This determination is calculated using predetermined algorithms that correspond to activity counts for each level of activity. Wrist-worn tri-axial accelerometers are an accurate assessment tool for measuring PA levels during pregnancy (van Hees et al., 2011), and provide the best compliance in order to obtain 24 hours/day wear data (van Hees et al., 2011).

Accurate PA measurement is critical to determine associations between maternal PA exposure and infant outcomes. When analyzing the cohort studies (Table 1), it is apparent that researchers have relied heavily on indirect measures of PA (i.e., self-report questionnaires or PA recall). About a third of the articles analyzed found significant associations between maternal leisure time PA and infant outcomes (Badon et al., 2018; Dahly et al., 2018; Harrod et al., 2014; Mudd et al., 2019; Norris et al., 2017). The remaining articles that subjectively assessed PA did not find significant associations with any infant outcomes. Additionally, one of three studies that objectively assessed PA, that also utilized a DXA, found a significant association between MVPA and infant fat mass (Bisson et al., 2017). The conflicting results observed may be due to the overestimation of leisure time PA and underestimation of sedentary time in subjective PA assessment (Brett et al., 2015; Sattler et al., 2018).

**Type of Exercise.** Another key factor that may modulate the relationship between PA and infant body composition is the mode or type of exercise that pregnant women participate in. Aerobic exercise is a type of training to improve cardiorespiratory endurance and involves rhythmic whole-body exercises (American College of Sports Medicine et al., 2018). Aerobic activities that are safe for pregnancy including walking, cycling, swimming, water aerobics, dance fitness, step class with a low step height, rowing, and running (if running prior to pregnancy) (Clapp et al., 2000). Anaerobic training is defined as short, intense bouts of physical activity fueled by energy sources within contracting muscles and independent of the use of inhaled oxygen as an energy source (American College of Sports Medicine et al., 2018). These activities include sprinting, high-intensity interval training (HIIT) and strength training. Resistance training aims to improve health and fitness by increasing musculoskeletal fitness (White et al., 2014). During pregnancy, utilizing relatively low weight with a higher number of repetitions appears to be the most safe and effective resistance training scheme to obtain benefits from strength training (Artal & White, S., 2003). While most strength exercises are safe (ACOG Committee on Obstetric Practice, 2020), activities that involve lying supine or moving in a manner that puts pressure on the uterine wall, as well as those that could cause overheating, risk of blunt trauma, or risk of falling should be avoided (Wing & Stannard, 2016).

Exercises can be classified as weight bearing (WB) (i.e., walking, running, dance fitness, step class, yoga and resistance training) or non-weight bearing (NWB) (i.e., swimming, cycling, water aerobics, and rowing). Maintaining pre-pregnancy intensity levels of WB activities throughout pregnancy (with physician consent) is safe during pregnancy (Clapp et al., 2002); however, some women may decrease intensity of WB activities during the third trimester to accommodate pelvic discomfort and physiological changes that occur (Fazzi et al., 2017). NWB activities may be the easiest to participate in throughout pregnancy as it minimizes joint stress, reduces fluid retention and reduces risk for injury (Prather et al., 2012).

Weight-bearing activities are the most common interventions used among RCT studies and researchers have found mixed results between WB exercise and infant outcomes. Since WB activities can vary greatly by type between RCT studies, it is difficult to draw a consensus on the impact on infant outcomes. While three studies from Clapp found infants of mothers in the WB intervention group were more likely to be smaller (i.e., significantly lower fat mass, fat mass percentage and PI) (Clapp et al., 1998, 2000; Clapp & Capeless, 1990), other studies have not found differences in infant anthropometrics between those born to women in the WB intervention and control groups (Barakat et al., 2009; Bisson et al., 2015; Clapp et al., 2002; Garnæs et al., 2017). Likewise, three RCT studies evaluated a non-WB intervention (i.e., home-based, moderate intensity, stationary bicycling program) (Hopkins et al., 2010; Seneviratne et al., 2016; Seneviratne et al., 2017). The birth weight, ponderal index and infant body composition (i.e., fat mass and fat mass percentage) were not significantly different between the infants born to mothers in the non-WB intervention and those of the control group (Hopkins et al., 2010; Seneviratne et al., 2016; Seneviratne et al., 2017).

Most observational studies and RCTs are unable to determine the effects aerobic exercise or strength training on infant outcomes because they are typically used in combination within a training program. Studies that evaluated an aerobic only intervention had mixed findings; several RCT studies found that the infants tended to be smaller from mothers of the combination (aerobic and strength training) intervention group than those of the control (Clapp et al., 1998; Clapp & Capeless, 1990; Hopkins et al., 2010; van Poppel et al., 2019). A few other studies evaluating aerobic only programs did not find any significant differences in infant anthropometrics between those infants of mothers in the intervention and those of the control (Clapp et al., 2002; Clark et al., 2019; S. Seneviratne et al., 2016; S. N. Seneviratne et al., 2017). Out of the few randomized control trials with resistance training, researchers have mostly found no correlations with infant outcomes (Barakat et al., 2009; White et al., 2014). One resistance training RCT that utilized moderate-to-vigorous intensities found that the infants of the moms in the intervention were significantly heavier (+310 g) than those born to the control women (Fieril et al., 2015); however, the difference did not remain after controlling for gestational age. Overall, the findings indicate that resistance training during pregnancy does not induce adverse infant outcomes and appears to be a safe, appropriate form of exercise during pregnancy.

**Intensity of Exercise.** For women with healthy pregnancies, the American College of Obstetrics and Gynecology (ACOG) recommend women participate in the same physical activity guidelines set by the American College of Sports Medicine (ACSM) for a healthy general population, which is ≥150 minutes a week of moderate-to-vigorous intensity exercise (ACOG Committee on Obstetric Practice, 2020; American College of Sports Medicine et al., 2018). All physical activities occur along a continuum of energy expenditure that can be matched with a corresponding MET (metabolic equivalent) value; one MET is equal to 3.5 mL $O_2$/kg/min (Norton et al., 2010). Intensity of exercises can be gauged using an absolute measure (i.e., heart rate or metabolic equivalents [METs]) or a relative measure such as a percentage of age-predicted max heart rate (APMHR) which can be estimated by 220-age (Norton et al., 2010). Studies that utilized heart rate to monitor intensity defined the groupings as light: 40-55% $HR_{max}$, moderate: 56-70% $HR_{max}$, and vigorous: 71-85% $HR_{max}$. In the cohort studies that utilized self-report/recall of PA participation during pregnancy, the self-reported time spent in each activity was computed to MET-hours and the average MET-hours at each intensity level was reported. Additionally, the cohort studies that utilized an objective measure of PA (accelerometer) recorded activity counts and utilized cut points to define the percentages of time spent in a range of intensities (sedentary-vigorous).

Current evidence indicates there may be differing trends in infant anthropometrics with various intensities. The articles evaluated in Table 1 are labeled with the intensities that were selected during clinical trials (RCTs) and the intensity ranges evaluated for cohort studies. With moderate-intensity, one review found that moderate PA participation throughout pregnancy, birth weight may be enhanced (heavier), while more vigorous regimens (vigorous PA) may result in a lighter infant (Pivarnik, 1998). Recently, other researchers have found similar findings amongst moderate PA with increases in birth weight (Clapp et al., 2000) and vigorous PA with decreases in birth weight [adiposity] (Bisson et al., 2017; Clapp & Capeless, 1990; Mudd et al., 2019). Specifically, Clapp and Capeless found infants of mothers who continued vigorous PA throughout pregnancy were significantly lighter (-310 g) than those who participated in light to moderate intensity PA (Clapp & Capeless, 1990). Likewise, two other researchers found that mothers who participated in moderate physical activity throughout pregnancy tended to increase birth weight due to lean mass, while infants of mothers who participated in vigorous physical activity at 36 weeks had significantly less fat mass and a lower fat percentage (Bisson et al., 2017; Mudd et al., 2019). In general, recent reviews have found vigorous intensity to be favorable in reducing the risk for delivering macrosomic infants (Beetham et al., 2019; Davenport et al., 2018); however, more research is needed to determine if the shift in infant fat mass and fat-free mass is due to intensity or from other exercise factors such as time point during pregnancy, frequency and duration.

**Frequency & Duration of Exercise.** An additional key factor that may modulate the relationship between physical activity and infant body composition is the frequency and duration of exercise that pregnant women participate in. Frequency is referred to as how many days per week or how often a pregnant woman engages in exercise within a week. Likewise, duration is considered as the length of one session or bout of physical activity ranging from 15 to 150 minutes. Intervention programs across RCT studies vary greatly in duration and frequency, many of which included supervised sessions and others that were home-based; exercise programs varied including one hour three times per week, 35-45 minutes three to five times per week and 40 minutes two to four times per week (Bisson et al., 2015; Clapp et al., 2000; Clark et al., 2019; Hopkins et al., 2010; Sklempe Kokic et al., 2018).

Considering the vast range of frequencies and durations between intervention programs, there is not a consensus for how this factor impacts infant outcomes. While some studies have evaluated the potential impact various amounts of frequency and/or duration of exercise during pregnancy has on birth weight (Barakat et al., 2016; Bisson et al., 2017; Pastorino et al., 2018), only two have evaluated the potential impact on infant body composition (Bisson et al., 2017; van Poppel et al., 2019). In a meta-analysis by Pastorino et al., the literature suggests that for each additional hour per week of moderate intensity physical activity during late pregnancy, infant birth weight was lower by 6.4 g (Pastorino et al., 2018). Likewise, Bisson et al. looked at activity during the first trimester and found that for each 1 MET/hour/week increase in exercise, birth weight was lower by 2.5 g (Bisson et al., 2017). Another RCT study beginning in the first trimester, exercising 3 days a week, with sessions lasting 50-55 minutes to meet the exercise guidelines, observed a significant decrease in the number of macrosomic babies amongst the training group compared to the control group (Barakat et al., 2016). Bisson et al. (2017) evaluated a range of durations of moderate and vigorous intensity exercise at 17 and 36 weeks; those who participated in only moderate physical activity for ≥90 minutes/day at 17 & 36 weeks tended to increase birth weight due to lean mass (Bisson et al., 2017). Findings from a recent RCT were also in line with the Bisson et al. (2017) study; compared to a usual care control group, the PA intervention group that engaged in five sessions a week with a duration between 30 to 45 minutes found a significant decrease in infant fat mass and fat mass percentage (van Poppel et al., 2019). In general, it is difficult to conclude how the frequency and duration of exercise impacts infant outcomes. While the ACOG has recommended 150 minutes of PA per week for general maternal and infant benefits (ACOG Committee on Obstetric Practice, 2020), it is still unclear what the threshold is to elicit an impact on infant body composition. Recent studies have concluded that various exercise durations positively impact infant body composition (Bisson et al., 2017; van Poppel et al., 2019), future research should evaluate the clinical threshold recommended by the ACOG and how it impacts infant body composition.

**Time Point of Exercise During Pregnancy.** Exercise during pregnancy is especially difficult to study considering how rapidly a pregnant woman's body is changing, and how these changes can influence how and when exercise is prescribed. There is no clear consensus on what time point is best to study exercise during pregnancy, and the entire nine months is too long for many study designs. Early in pregnancy, there is risk for experiencing a loss, so most RCT studies do not study women in the first trimester to avoid this risk. The majority of pregnancy studies occur during the second and/or third trimesters. However, results have to be interpreted carefully as one cannot generalize outcomes for any other timepoints beyond the ones studied (e.g. if a study shows PA during the second trimester improves infant outcomes, this cannot be generalized to PA during the first or third trimester). The timepoints for each study evaluated are listed in Table 1.

Each trimester of pregnancy serves as an important milestone of growth for a fetus. The greatest amount of physical growth occurs in the third trimester where a fetus can double in size between 28 and 32 weeks as well as gain over half-pound a week during the last month of pregnancy (*Stages of Pregnancy*, 2016). While the timepoints for each study varies, there is some evidence that exercise may have greater influence on infant outcomes during late pregnancy compared to exposure during early or mid-pregnancy (Pastorino et al., 2018).

Clapp et al. found in two separate studies that mothers who maintained >50% of pre-pregnancy exercise levels during late pregnancy (Clapp & Capeless, 1990) and those who maintained a high volume of exercise during the third trimester (Clapp et al., 2002) delivered infants who were significantly smaller (i.e., lower birth weight and decreased fat mass/fat mass percentage [skinfolds]) than those mothers who decreased exercise volume during late pregnancy. Similarly, other studies have found associations between exercise during late pregnancy and significant decreases in infant fat mass (Bisson et al., 2017; Harrod et al., 2014; Mudd et al., 2019). In essence, engaging in late pregnancy PA may have greater impacts on infant outcomes than PA during early or mid-pregnancy.

### Gap in the Literature

Despite the evidence-based information available regarding the maternal benefits from physical activity during pregnancy, it is clear that there is not a consensus over the benefits for infants. Certainly, the lack of standardized protocols and continued use of subjective measurements for physical activity interventions contributes to the difficulty in interpreting the infant outcomes. Identifying the modifying factor(s) (i.e., frequency, intensity, duration, type, timepoint during pregnancy) will be critical in establishing the impact PA during pregnancy has on infant anthropometrics. Specifically, future studies should evaluate PA during late pregnancy and/or with varying intensities as the evidence suggests that the impact may be time-sensitive (Harrod et al., 2014; Mudd et al., 2019; Pastorino et al., 2018) and intensity-specific (Bisson et al., 2016; Clapp &

Capeless, 1990; Mudd et al., 2019; Pastorino et al., 2018). Similarly, the tools utilized to measure infant outcomes have not been standardized across studies. Because infant ADP is the new gold standard for assessing infant body composition, more research is needed to determine the role of physical activity during pregnancy on infant body composition utilizing this methodology.

*The primary purpose of this study is to determine the association between objectively measured physical activity (accelerometry) during late pregnancy and infant body composition utilizing the gold standard method for body composition (PEA POD).*

## Methods

### Participants

Healthy pregnant women with no underlying health conditions were recruited via word of mouth, in response to study flyers (Appendix A) that were posted at local obstetrics/gynecology (OB/GYN) clinics and given at local pregnancy health fairs, and a listserv email announcement was sent to institutional faculty and staff.  Women between the ages of 18-44 years who had a confirmed singleton pregnancy were recruited between 34-39 weeks of gestation.  Women who were experiencing a multiple gestation pregnancy, had pre-existing health conditions that prohibited physical activity, physician clearance withheld, deliveries before 37 weeks of gestation, and those who were not delivering at The Medical Center at Bowling Green, were excluded from the study.

### Procedures

All study procedures were approved by the Institutional Review Board of Western Kentucky University (IRB 16-229).  The participants were each given a written informed consent and a written informed assent for infants (Appendix B) prior to the hospital visit for infant measurements.  In order to ensure the safety of all participants, physician clearance was required for participation (Appendix C).  The participants received compensation after completing the surveys ($10) and after infant anthropometrics were obtained ($25).

*Physical Activity and Survey Data Collection*

Pregnant women were contacted between 34-39 weeks gestation and met individually with a study team member to gather demographic data and complete a series of surveys. The first survey was the *General Demographics Survey* (Appendix D) which provides basic information on the participant's age, parity, weight/height, socioeconomic status, race, educational background, and baseline current physical activity level. Physical activity levels were further assessed using the Pregnancy Physical Activity Questionnaire *PPAQ* (Chasan-Taber et al., 2004)(Appendix E) and through a wrist-worn ActiGraph GT9X Link Accelerometer (ActiGraph LLC, Pensacola, FL). The PPAQ is a validated, semi-quantitative questionnaire for pregnant women to classify their time spent participating in 32 different activities per day across five different categories-household/caregiving, occupational, sports/exercise, transportation, and in-activity (Chasan-Taber et al., 2004). Self-reported time spent in each activity is computed to MET hours and the average MET hours per week were classified by type of activity and intensity level.

The ActiGraph GT9X link accelerometer was given to the participant after survey completion to objectively measure physical activity levels. Wrist-worn tri-axial accelerometers are an accurate assessment tool for measuring physical activity levels during pregnancy (da Silva et al., 2019; Freedson et al., 1998) and can provide the best compliance in order to obtain 24 hours/day wear data (van Hees et al., 2011). The ActiGraph accelerometer was worn by the participant on their non-dominant wrist for 24 hours/day over seven consecutive days. Data was collected at 30 Hz and through the ActiLife software (v6.13.4, ActiGraph LLC, Pensacola, FL), the percentage of time spent sedentary and participating in a range of activity levels (light, moderate, and vigorous) was determined. This determination was calculated using predetermined algorithms that correspond to activity counts for each level of activity: sedentary: 0-99 counts/min, light: 100-1951 counts/min, moderate: 1952-5724 counts/min (Freedson et al., 1998). In addition to the activity counts, the average kcals per day was recorded for total energy expenditure and the percent of time in moderate to vigorous physical activity (MVPA) to identify those mothers who met the ACSM guidelines of ≥150 minutes of moderate-to-vigorous physical activity per week.

*Infant Measurements*

Infant anthropometrics were collected following the *Infant Measurement Protocol* (Appendix F) between 24-48 hours after birth at the participant's bedside at The Medical Center at Bowling Green. Taking infant measurements at the participant's bedside before the mom/baby are discharged allows for mom/baby to adjust to birth while minimizing drop out and the effects of the environment (i.e. feeding practices) on the infant birth weight since the two-week period following birth has the greatest amount of fluctuations in birth weight (Crossland et al., 2008). Abdominal and head circumferences (Gulick II Tape Measure, Country Technology Inc., Gays Mills, WI) were measured and recorded using well-established protocols (Johnson & Engstrom, 2002). Skinfold anthropometry was then performed to estimate the infant's body fat percentage.

Folds of the skin at four sites-triceps, subscapular, thigh, and hip- were measured by lifting the skin with the thumb and index finger and the thickness of each fold was pressed with a caliper (Harpenden Skinfold Caliper, Baty International, United Kingdom) twice and recorded. If there was a difference greater than 2mm between two measurements, a third measure was taken. Two measurements in agreement were averaged and used for analysis using the standardized equation based on the infant's gender, ethnicity, age and birth weight (Deierlein et al., 2012) to estimate fat mass.

$$Fat\ mass(kg) = -0.012 - 0.064 \times gender + 0.024 \times postnatal\ age(days) - 0.150 \times weight(kg) + 0.055 \times weight(kg)^2 + 0.046 \times ethnicity + 0.020 \times \sum 3\ skinfolds\ (mm)$$

*Boys=1, girls=0; ethnicity non-Hispanic=0; skinfolds=triceps, subscapular, thigh

Fat-free mass was calculated by subtracting the estimated fat mass from birth weight. Percent body fat and percent fat-free mass was found by dividing fat mass/fat-free mass respectively by birth weight and multiplying by 100.

Infant adiposity was then assessed by air-displacement plethysmography (ADP) using the PEA POD (COSMED Inc, Concord, CA, USA) which is now regarded as the neonatal gold standard method for measuring body composition changes (Barbour et al., 2016; F. P. McCarthy et al., 2016). The PEA POD is a reliable measure and has been validated in infants against the four-compartment model (Ellis et al., 2007). Infant ADP (PEA POD) has increased in widespread use as it is simple to use, fast, and doesn't require an infant to lie still. ADP takes about five minutes to complete an assessment that uses direct measures of body mass with a precise scale divided by estimated body volume through air-displacement in an enclosed, air-tight chamber, to find body density. Percent body fat can be calculated based on assumed densities of fat mass and fat-free mass using the two-compartment model of body composition.

<u>Statistical Analysis</u>

Data was collected, stored, and managed using Research Electronic Data Capture (REDCap), hosted at Western Kentucky University. All data analyses were conducted using SPSS Statistics 25.0 (IBM, 2009, Armonk, New York). Normality of the distribution for each variable was tested using Kolmogorov-Smirnov tests. All non-normally distributed data was log-transformed. Pearson product-moment correlation coefficients were performed to assess the degree of the relationship between variables. Partial correlations were used to adjust for potential confounders. When looking at differences between various groups, T-tests or Chi-square tests were used to assess differences between groups. The p-value was set at 0.05 to denote statistical significance.

## Results

Maternal Physical Activity

Maternal demographics are shown in Table 2.

**Table 2. Maternal Demographics**

| | **Maternal Characteristics (n=55)** |
|---|---|
| **Age (years)** | 30.8±4.5 |
| **Pre-pregnancy height (cm)** | 166.2±6.9 |
| **Pre-pregnancy weight (kg)** | 70.8±18.2 |
| **Pre-pregnancy BMI (kg/m$^2$)** | 25.8±6.4 |
| **Gestational Weight Gain (kg)** | 15.0±6.3 |
| **Household Income ($)** | 91,500±48,600 |
| **Parity** | |
| ***Nulliparous*** | 23 (42%) |
| ***Multiparous*** | 32 (58%) |
| **Ethnicity** | |
| ***Caucasian*** | 49 (89%) |
| ***African American*** | 5 (9%) |
| ***Asian*** | 1 (2%) |
| **Education** | |
| ***High School*** | 2 (4%) |
| ***Some College*** | 3 (5%) |
| ***Trade/Vocational School*** | 2 (4%) |
| ***College Degree*** | 22 (40%) |
| ***Post-Graduate Degree*** | 26 (47%) |
| **Current Exercise at Baseline** | |
| ***None*** | 16 (29%) |
| ***Once a week*** | 13 (24%) |
| ***2-3 times/week*** | 15 (27%) |
| ***4-5 times/week*** | 8 (15%) |
| ***Everyday*** | 3 (5%) |

Of the 55 women that participated, only 51 had valid ActiGraph data (Table 3). According to the objective measure of PA (ActiGraph), the women in the study primarily engaged in various amounts of light PA, spent more time in sedentary activities, and did not engage in any vigorous activities. The women reported on the PPAQ that they spent the majority of their time during the week in light-to-moderate activities; by category the activities women participated in were mostly household work and very little time in sports and exercise activities. Comparing the two measures, the women reported (PPAQ) that they spent less time sedentary and more time in light-to-moderate activities which was not reflected by the PA data recorded by the objective measure (ActiGraph).

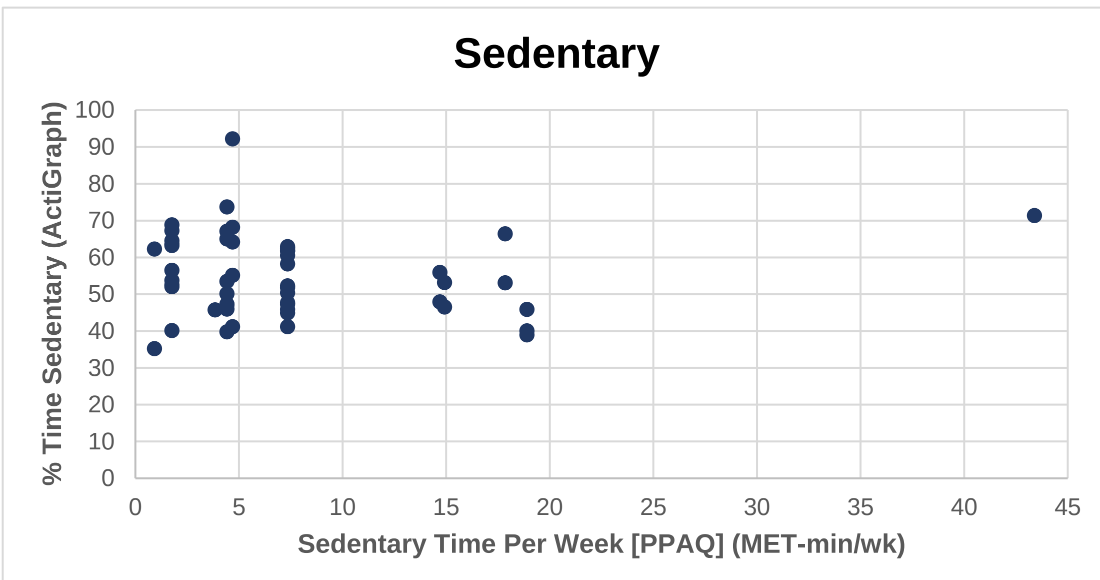
**Table 3. Late-Pregnancy Physical Activity**

| PPAQ | Mean Time (n=55) | ActiGraph | Mean % Time (n=51) |
|---|---|---|---|
| **Inactivity**<br>**Sedentary activity/week** | 12.6±11.8<br>7.8±7.4 | **% time sedentary** | 54.94±11.1 |
| **Light activity/week** | 120.3±46.8 | **% time light** | 33.56±8.9 |
| **Moderate activity/week** | 282.9±1611 | **% time moderate** | 11.49±4.7 |
| **Vigorous activity/week** | 2.7±5.6 | **% time vigorous** | 0±0 |
| **Total light activity & above** | 188.1±100 | **% MVPA** | 11.49±4.7 |
| **Total activity/week** | 195.7±92.5 | **Average kcal/day** | 1482.67±634.3 |
| **Transportation**<br>**Occupational**<br>**Household & Caregiving**<br>**Sports & Exercise** | 24.4±19.6<br>64.6±67.1<br>84.3±55.5<br>9.8±9.5 | | |

Age was positively correlated to MVPA (r=0.373, p=0.007). Women with a greater household income tended to be less sedentary (% Sedentary Time ActiGraph: r=-0.357, p=0.020; Sedentary Time PPAQ: r=-0.483, p=0.001) and more active (% Moderate Activity ActiGraph: r=0.420, p=0.006; % MVPA ActiGraph r=0.420, p=0.006). While women with a higher education level tended to be less sedentary (% Sedentary Time ActiGraph: r=-0.387, p=0.005), there was not a significant correlation between education level and moderate to vigorous physical activity participation (% MVPA ActiGraph r=0.27, p=0.054).

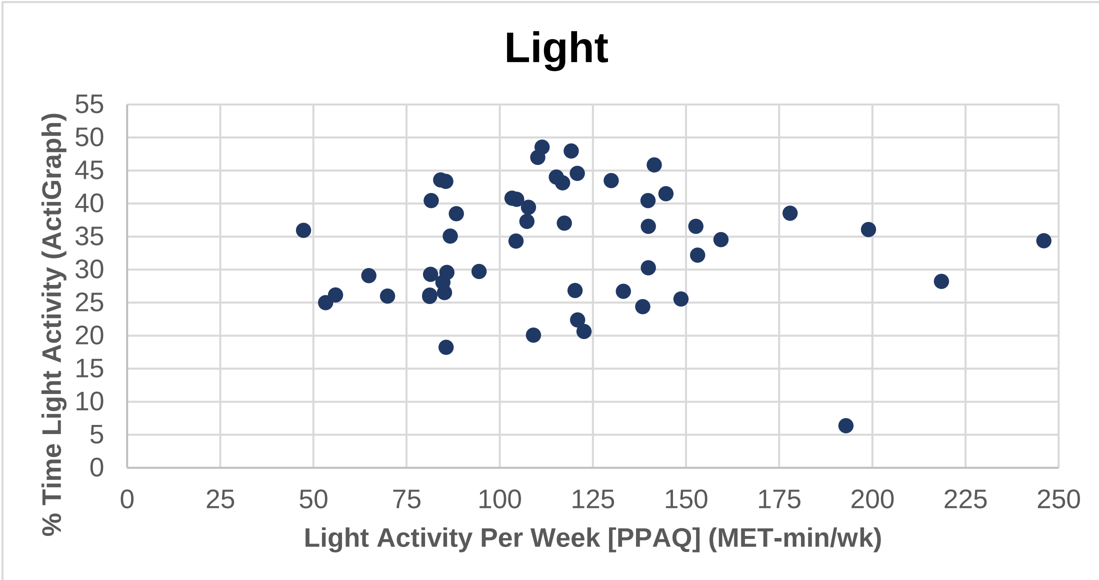
The physical activity data collected by the PPAQ and the ActiGraph did not correlate well at any intensity level (i.e., sedentary/sedentary, light/light, moderate/moderate); Sedentary (r=-0.094, p=0.512) is shown in Figure 1; Light (r=-0.021, p=0.884) shown in Figure 2; Moderate (r=0.031, p=0.831) shown in Figure 3. In the figures below (Figures 1-3), the unit measures vary to accompany the range of data collected.

**Figure 1. Sedentary Time Correlation**



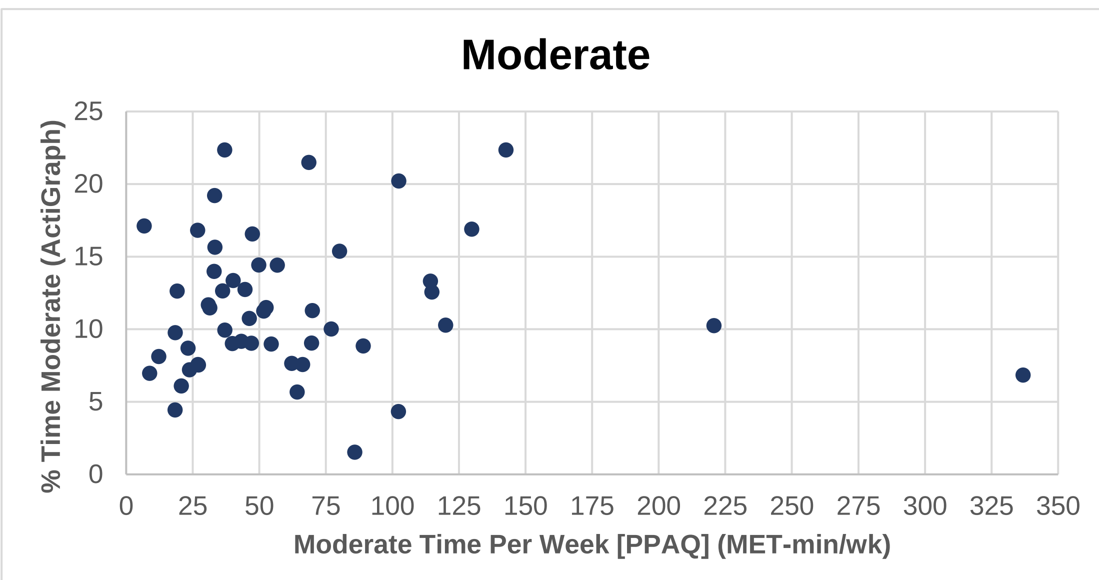

*Note.* Sedentary activity measures did not correlate; r=-0.094, p=0.512

**Figure 2. Light Activity Correlation**




*Note.* Light activity measures did not correlate; r=-0.021, p=0.884

**Figure 3. Moderate Activity Correlation**




*Note.* Moderate activity measures did not correlate; r=0.031, p=0.831

<u>Infant Outcomes</u>

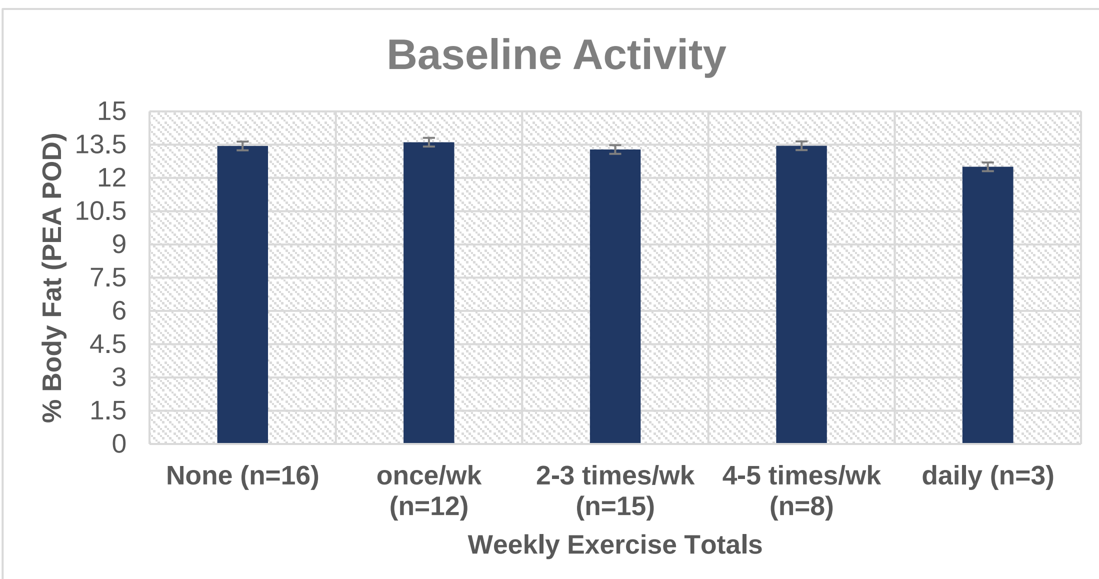
Infant demographic and anthropometric data are shown in Table 4.

**Table 4. Infant Demographics & Anthropometrics**

| | **Infant Demographics & Anthropometrics (n=55)** |
|---|---|
| **Infant Age at Measurement (days)** | 1.3±0.7 |
| **Infant Gestational Age (weeks)** | 39.5±1.1 |
| **Delivery Method** | |
| ***Vaginal*** | 35 (73%) |
| ***Cesarean*** | 13 (27%) |
| **Infant Gender** | |
| ***Male*** | 25 (46%) |
| ***Female*** | 30 (54%) |
| **Birth Weight (kg)** | 3.4±0.5 |
| **Birth Length (cm)** | 50.7±6.2 |
| **Circumferences (cm)** | |
| ***Head*** | 34.3±9.5 |
| ***Abdominal*** | 33.5±8.8 |
| **Skin Folds Average (mm)** | |
| ***Triceps*** | 5.2±1.7 |
| ***Subscapular*** | 4.4±1.05 |
| ***Hip*** | 3.6±1.2 |
| ***Thigh*** | 6.3±1.8 |
| **SF Estimated Body Fat %** | 15.04±4.2 |
| **PEA POD** | |
| ***% Body fat*** | 13.4±3.9 |
| ***% Fat-free mass*** | 86.2±5.2 |
| ***Fat mass (kg)*** | 0.47±0.2 |
| ***Fat-free mass (kg)*** | 2.9±0.4 |
| ***Body mass (kg)*** | 3.3±0.6 |
| ***Body volume*** | 3.2±0.6 |
| ***Body density*** | 1.04±0.009 |
| ***Fat mass density*** | 0.9±0.00025 |
| ***Fat-free mass density*** | 1.06±0.002 |
| ***Body surface area*** | 2300±233.9 |
| ***Thoracic gas volume*** | 0.1±0.016 |

There were no significant correlations in infant percent body fat (PEA POD) between categories of baseline self-reported physical activity levels (Figure 4; p=0.995). There were no significant correlations between infant percent body fat (PEA POD) and late-pregnancy activity levels measured objectively with the ActiGraph [(Sedentary, Figure 5, r=-0.072, p=0.756) (Light, Figure 6, r=-0.002, p=0.990)(Moderate, Figure 7, r=0.208, p=0.367)(MVPA, Figure 8, r=0.203, p=0.377)], even after controlling for infant's gestational age, gestational weight gain, pre-pregnancy BMI, and parity.

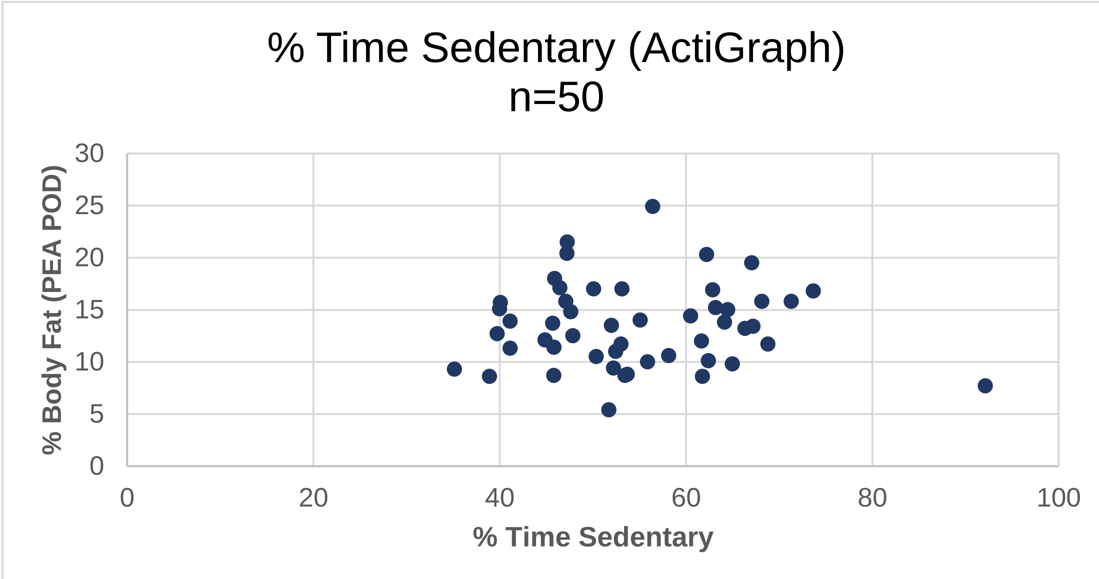
**Figure 4. % Body Fat by Baseline Activity Levels**




*Note.* **General Survey Question-** ***In a typical week, with a workout lasting at least 30 minutes to an hour, how are you currently exercising?***

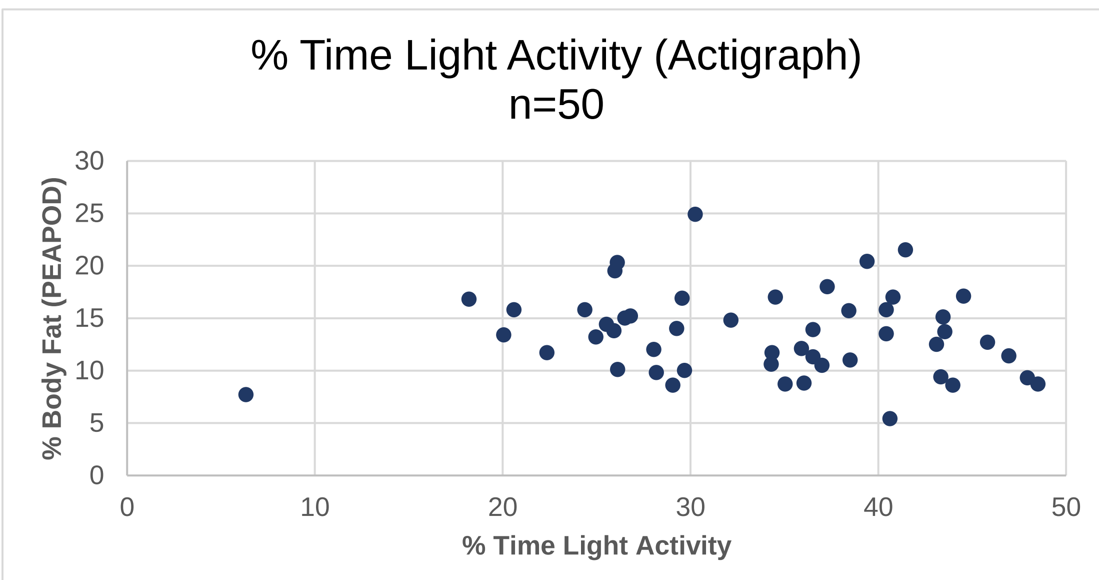
% Body Fat not significantly different between groups; p=0.995.

**Figure 5. % Body Fat by ActiGraph Sedentary Time**



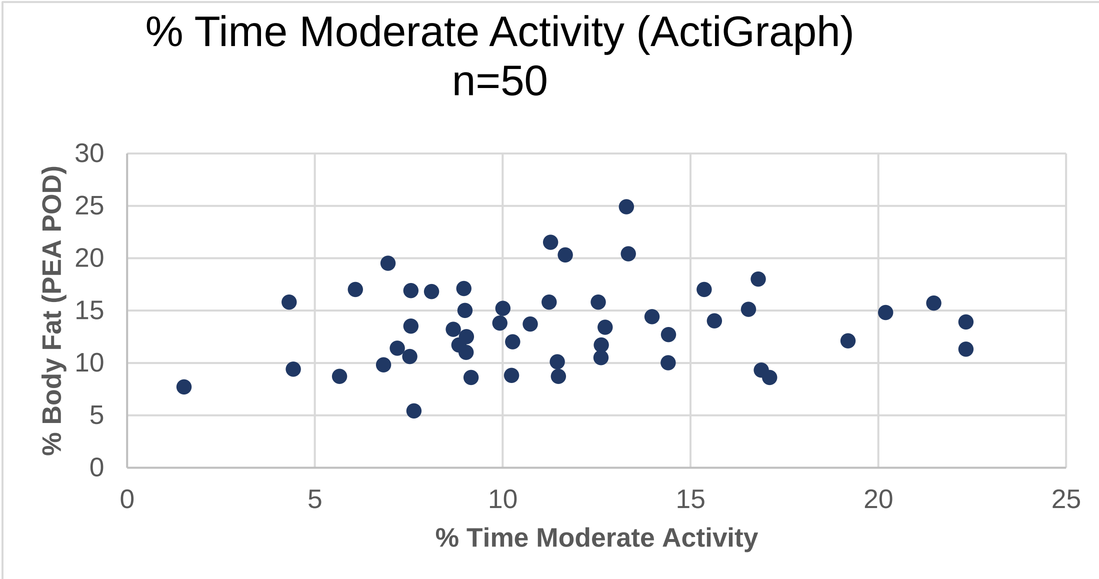

*Note.* % Body Fat did not correlate; r=-0.072, p=0.756

**Figure 6. % Body Fat by ActiGraph Light Activity**



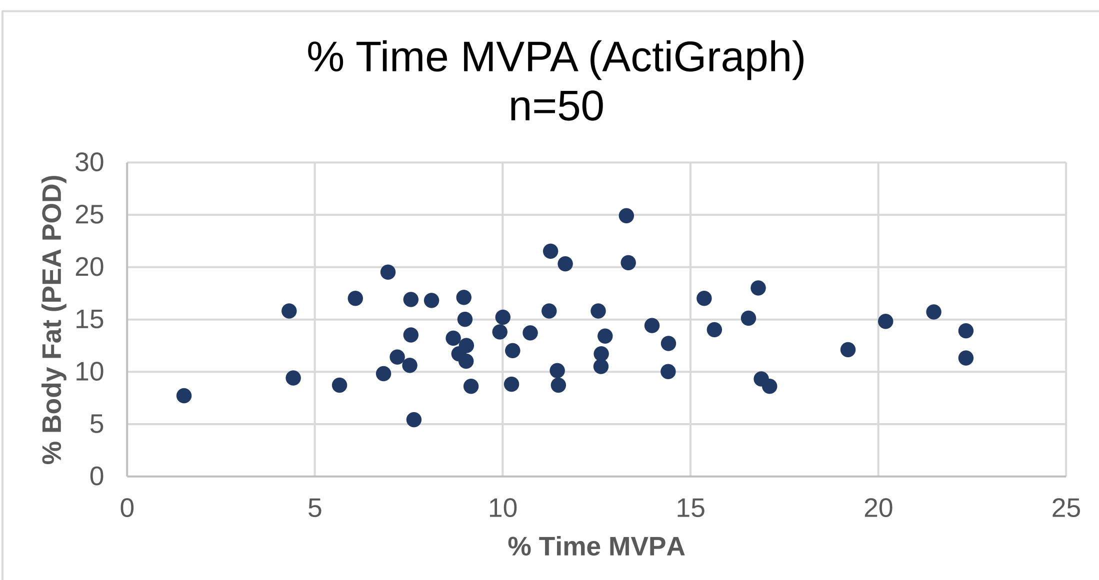

*Note.* % Body Fat did not correlate; r=-0.002, p=0.990

**Figure 7. % Body Fat by ActiGraph Moderate Activity**




*Note.* % Body Fat did not correlate; r=0.208, p=0.367

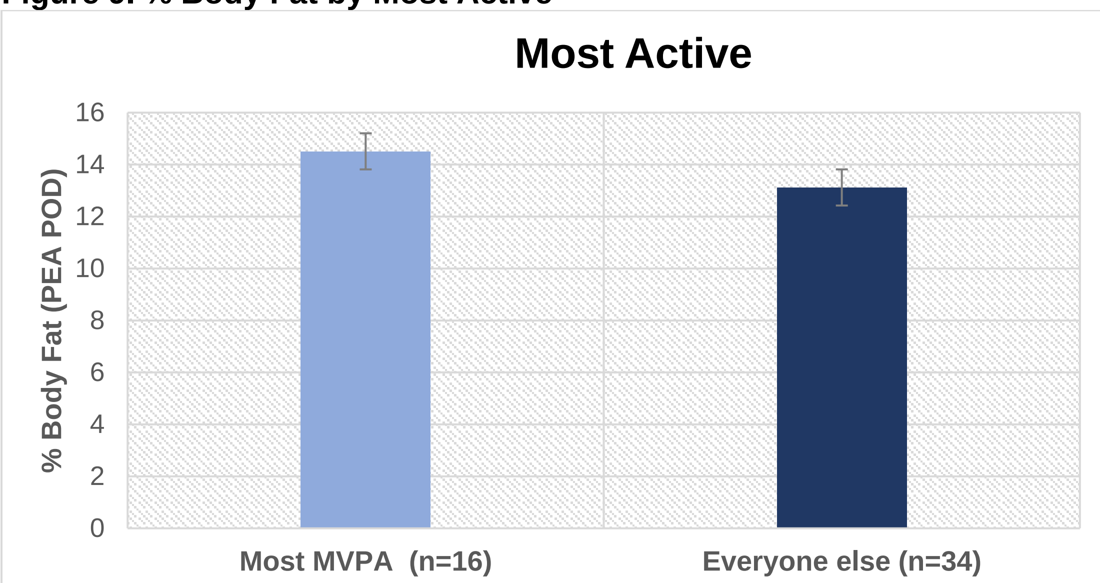
**Figure 8. % Body Fat by ActiGraph MVPA**




*Note.* % Body Fat did not correlate; r=0.203, p=0.377

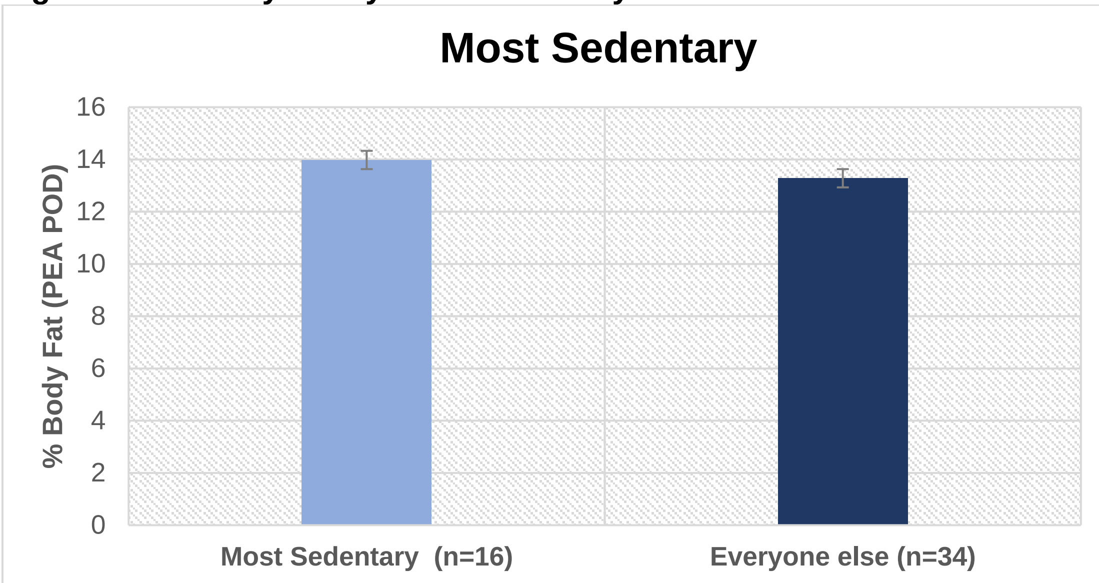
When pulling out the most active mothers (Figure 9), there was no difference between the most active women and the rest of the participants in terms of infant body composition (%MVPA, ActiGraph) (p=0.252). There was also no significant difference in infant body composition when grouping and comparing the most sedentary women to everyone else (Figure 10, p=0.568). When comparing the most sedentary (% Sedentary, ActiGraph) and most active women (%MVPA, ActiGraph), there was not a significant difference in infant body composition (Figure 11, p=0.377).

**Figure 9. % Body Fat by Most Active**



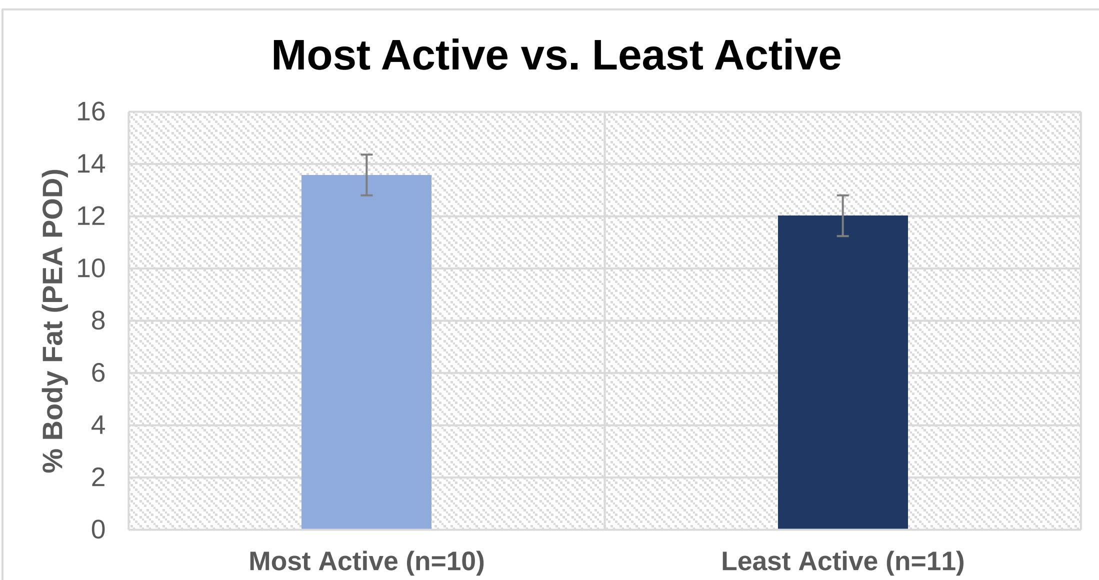

*Note.* % MVPA ActiGraph; % Body Fat not significantly different, p=0.252

**Figure 10. % Body Fat by Most Sedentary**




*Note*. ActiGraph; % Body Fat not significantly different, p=0.568

**Figure 11. Most Active vs. Least Active**

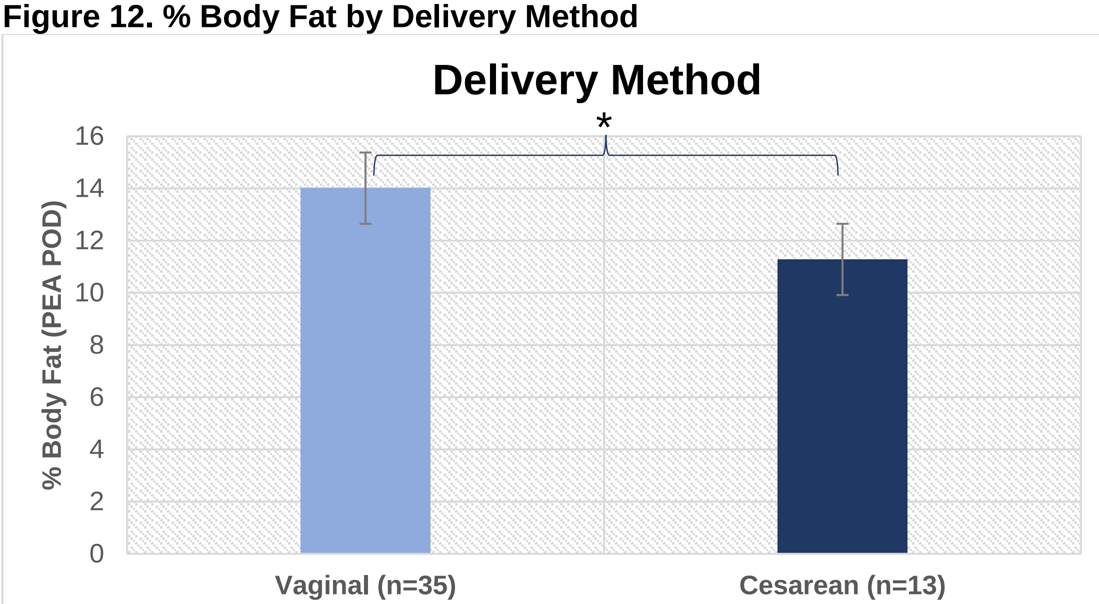



*Note.* ActiGraph; % Body Fat not significantly different, p=0.377

Ancillary Findings

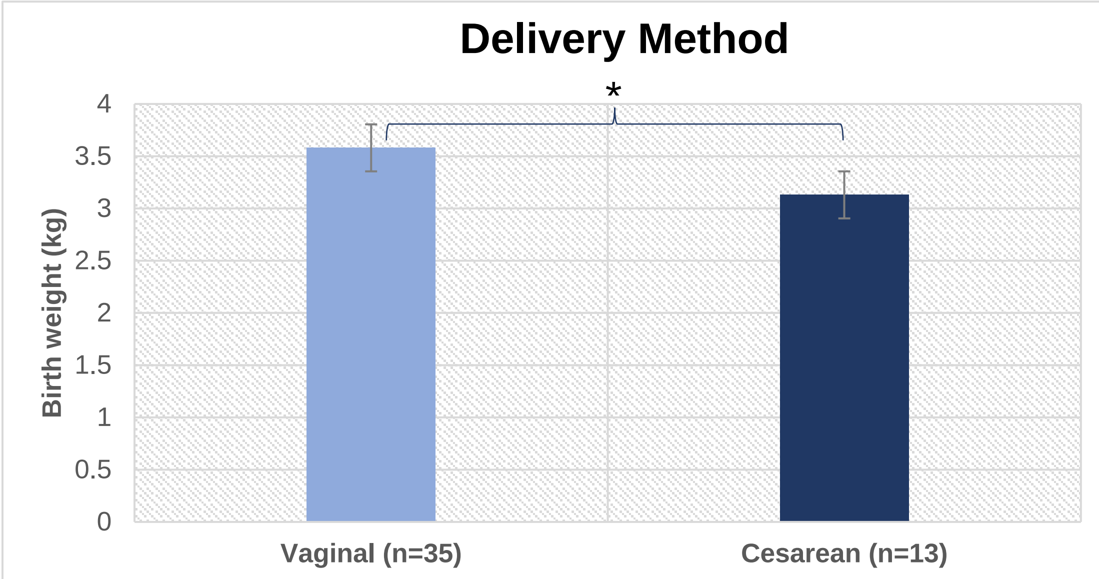
Women who had a vaginal delivery delivered infants with a higher percentage of body fat (PEA POD) (Figure 12, p=0.040). This was also observed for birth weight in that infants born through a vaginal birth tended to be heavier (Figure 13, p=0.002). Infants born through a cesarean section delivery were on average were born a week earlier than those born through vaginal birth. However, even after controlling for the infant's gestation age, both the birth weight and percent body fat remained significantly different between infants born vaginally versus infants born via Cesarean.

**Figure 12. % Body Fat by Delivery Method**




*Note. *p<0.05 significance between groups,* p=0.040

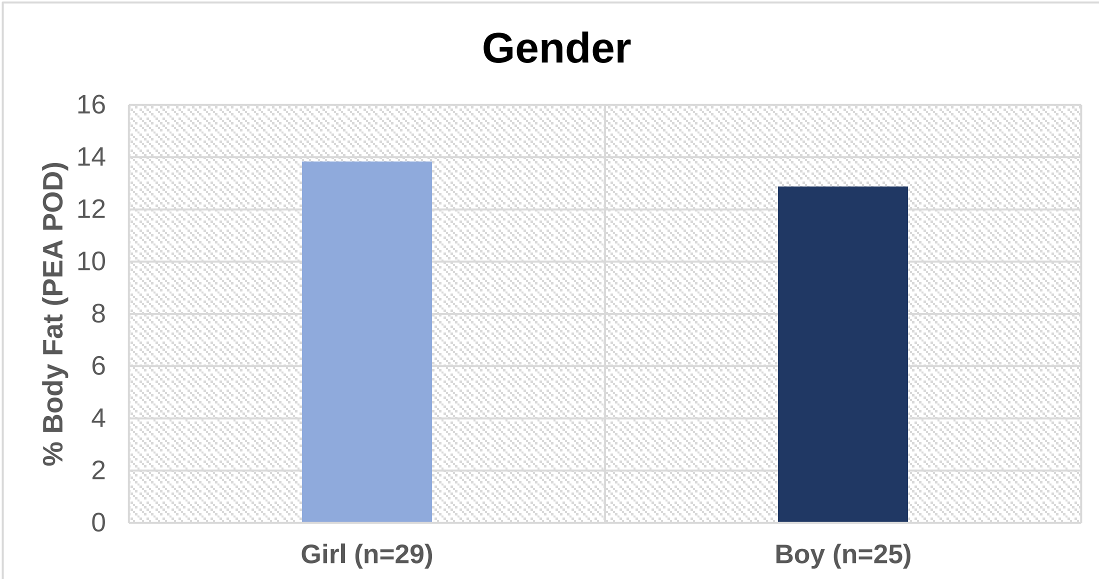
**Figure 13. Birth Weight by Delivery Method**




*Note. *p<0.05 significance between groups,* p=0.002

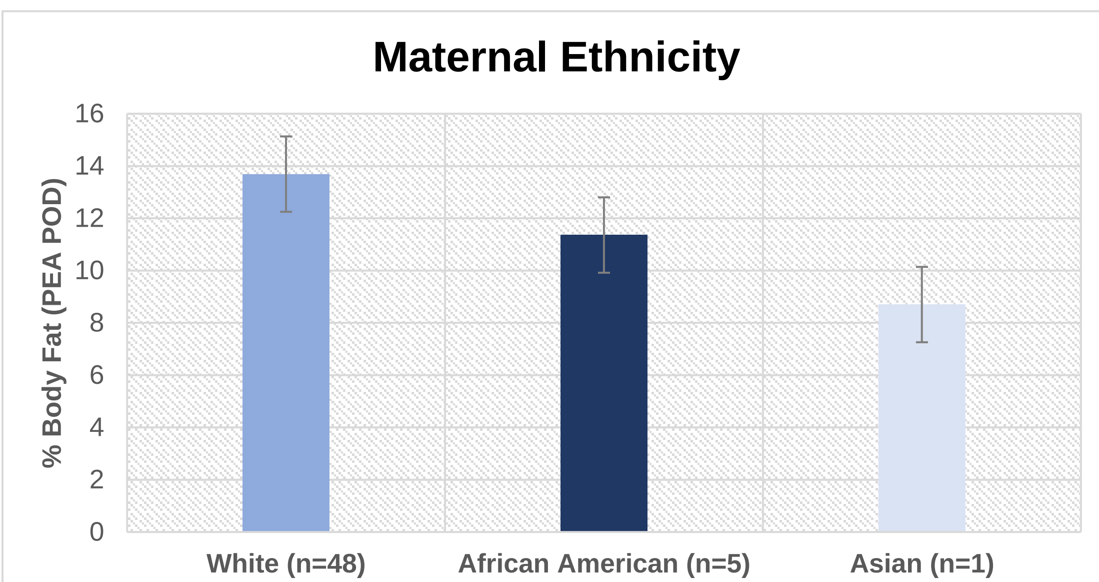
There were no significant differences in percentage of infant body fat (PEA POD) between males and females (12.9 ± 3.8% vs. 13.8 ± 4.0%, p=0.730). No significant difference in infant percent body fat (PEA POD) was observed between women of different ethnicities (p=0.217). Women who had other children tended to have babies with a larger percentage of body fat (PEA POD) (14.2 ± 3.9% vs. 12.3 ± 3.8%, p=0.088). Infants born Large-for-Gestation Age (LGA) had a trend towards higher percent of body fat (PEA POD) but it was not statistically significant (15.57 ± 2.04 vs. 13.06 ± 4.02, p=0.142).

**Figure 14. % Body Fat by Infant Gender**



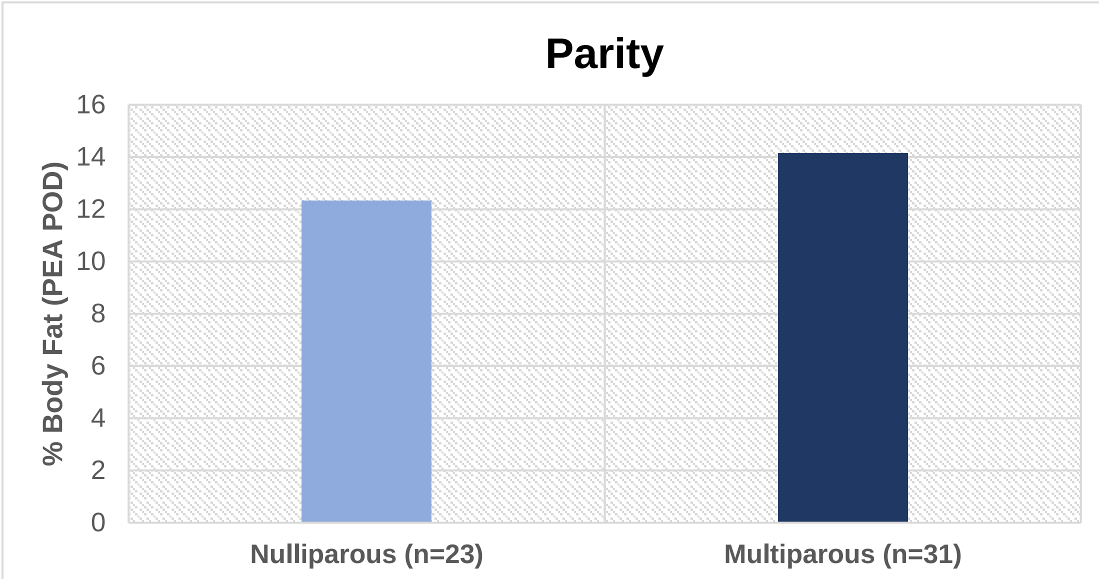

*Note. Girls* 13.8 ± 4.0% vs. *Boys* 12.9 ± 3.8%, p=0.730

**Figure 15. % Body Fat by Maternal Ethnicity**



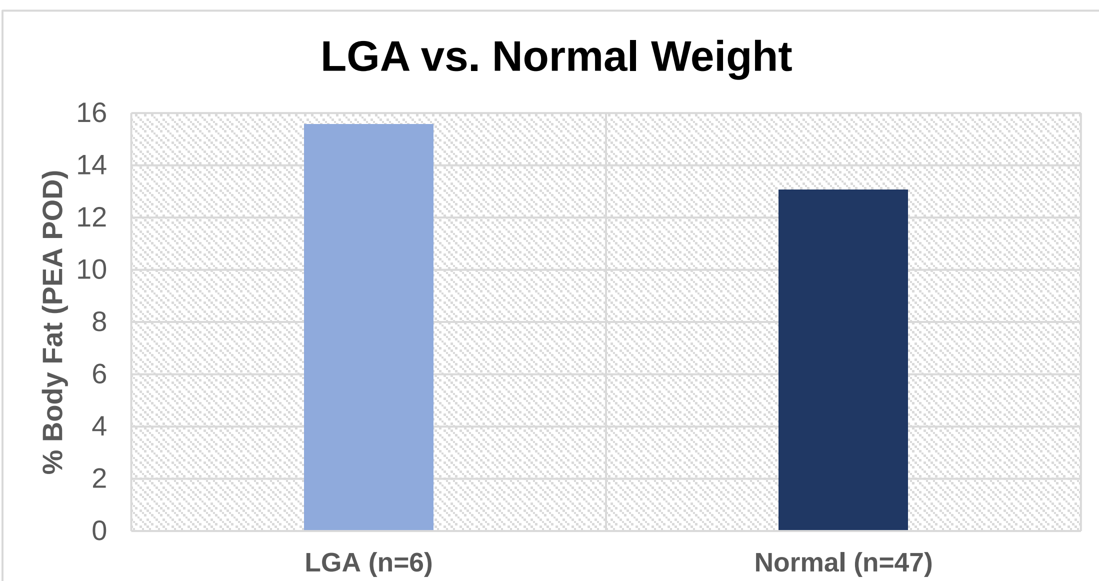

*Note.* No significant difference in % Body Fat between maternal ethnic groups, p=0.217

**Figure 16. % Body Fat by Parity**




*Note. Nulliparous* 12.3 ± 3.8% vs. *Multiparous* 14.2 ± 3.9%, p=0.088

**Figure 17. % Body Fat by Birth Weight (LGA)**




*Note. LGA* 15.57 ± 2.04 *vs. Normal BW* 13.06 ± 4.02, p=0.142

Other infant anthropometrics measured at birth correlated well with the percent of body fat measurements from the PEA POD, shown in Table 5. The percentage of infant body fat (PEA POD) did not correlate with other maternal demographics.

**Table 5. PEA POD Correlations**

| | **% Body Fat (PEA POD) Correlations** |
|---|---|
| **Birth weight** | (r=0.384, p=0.004) |
| **Infant head circumference** | (r=0.369, p=0.007) |
| **Infant abdominal circumference** | (r=0.275, p=0.049) |
| **Skinfolds** | |
| ***Tricep*** | (r=0.338, p=0.012) |
| ***Subscapular*** | (r=0.442, p<0.001) |
| ***Hip*** | (r=0.467, p<0.001) |
| ***Thigh*** | (r=0.350, p=0.010) |
| ***% Body fat*** | (r=0.523, p<0.001) |
| **Pre-pregnancy weight** | (r=-0.177, p=0.200) |
| **Pre-pregnancy BMI** | (r=-0.231, p=0.096) |
| **Maternal pregnancy end-weight** | (r=-0.159, p=0.250) |
| **Gestational weight gain** | (r=0.126, p=0.362) |

# Discussion

## Maternal Physical Activity

The aim of this study was to determine the association between maternal physical activity during late pregnancy and infant anthropometrics at birth. We did not observe any significant correlations between late pregnancy maternal physical activity levels (sedentary, light, moderate) assessed via accelerometry and PPAQ with infant body composition (PEA POD), even after controlling for infant's gestational age, gestational weight gain, pre-pregnancy BMI, and parity. Further, when the most sedentary women and most active women were compared, there were no significant differences observed in infant body fat percentage (PEA POD). In addition, there were secondary findings concerning infant body composition which included: infants born vaginally were heavier and tended to have a higher percentage of body fat (PEA POD) than those infants who were delivered by cesarean section (C/S); infants born Large-for-Gestation Age (LGA) had a higher percentage of body fat (PEA POD) but this finding was not statistically significant; with regard to parity, infants second (or higher) in the birth order tended to have a higher percentage of body fat (PEA POD).

Physical activity was assessed through self-report (PPAQ) and accelerometer (ActiGraph); however, the data did not correlate well between measures at any intensity level (i.e., sedentary vs. sedentary, light vs. light, moderate vs. moderate). While the PPAQ is commonly used across the literature, it has been found to overestimate leisure time PA across all activity categories (Brett et al., 2015). Likewise, an accelerometer is known to be the gold standard for objectively measuring free-living PA (Troiano et al., 2014) and has been found to be a more reliable and accurate method for assessing MVPA during pregnancy (da Silva et al., 2019). Therefore, we utilized the accelerometer data for analyzing PA correlations with infant anthropometrics.

### Infant Anthropometric Outcomes

*Main Findings*

Contrary to our hypothesis, there were no significant correlations between maternal physical activity during late pregnancy and infant anthropometrics. Even after controlling for maternal gestational weight gain, pre-pregnancy BMI, parity, and infant's gestational age, there were no significant correlations observed between infant percent body fat (PEA POD) and late-pregnancy PA levels (i.e., sedentary, light, MVPA).

Our findings are consistent with previous studies that have also not observed significant differences in infant anthropometrics between active and inactive women (or no association between maternal pregnancy PA levels and infant body composition) (Bisson et al., 2015; Joshi et al., 2005; Rao et al., 2003; Seneviratne et al., 2017; Tinius et al., 2016). The fact that maternal physical activity levels did not appear to correlate well with infant adiposity may suggest the baby is protected from some aspects of maternal stimuli (whether positive or negative). To elaborate, previous research suggests that increasing regular exercise (up to an undetermined threshold) throughout pregnancy may provide a protective effect against infant birth weight extremes (Clapp & Capeless, 1990;

Owe et al., 2009). The protective effect may ensure a birth weight within the normal range (i.e., 2500 - 4000 g) occurs to aid in delivery. Specifically, the literature suggests that moderate PA may help decrease birth weight in the upper extremes (LGA) with increases in regular PA throughout pregnancy (Owe et al., 2009) while subsequently decreasing the rate of birth weights in the lower extremes (SGA)(Clapp & Capeless, 1990). However, previous research has found a trend that increasing total volumes of higher intensity may lead to a higher risk of an infant born SGA (Harrod et al., 2014; Trak-Fellermeier et al., 2019); yet, the specific threshold where the PA trend shifts from protective to increased risk for SGA has not been determined. These data provide insight to the complicated relationship between maternal activity and infant anthropometrics; assuming a linear relationship is likely oversimplifying this relationship.

In our study, we speculate that the trend of a protective effect against birth weight extremes may be present in our findings as the majority of the women appeared to participate in light-to-moderate PA during late pregnancy and we observed six infants with LGA and none with SGA. In turn, the trend observed could suggest a positive/favorable effect of physical activity on birth weight.

While our results are consistent with some of the previous literature, there are several other studies with similar methodologies that have found a significant decrease in infant percent body fat with increases in maternal physical activity (Bisson et al., 2017; Clapp & Capeless, 1990; Harrod et al., 2014; Mudd et al., 2019; Trak-Fellermeier et al., 2019; van Poppel et al., 2019). Our study design differed from these studies by time point during pregnancy, cohort design rather than an intervention, method for collecting physical activity data (if it was not an intervention) and the method for assessing infant body composition.

Although previous researchers have suggested that the modifying factor may be late pregnancy PA (Pastorino et al., 2018; Pivarnik, 1998), some of the studies found differences in infant body composition associated with PA during early pregnancy (15-20 weeks)(Bisson et al., 2017; Dahly et al., 2018; Norris et al., 2017). However, these differences were only significant at higher intensities of PA and with longer durations for each bout of PA. Therefore, we speculate our results did not align with the CORK Cohort Study (2018), even though both collected PA data during late pregnancy, as a result of the women in our study not reaching a higher intensity of PA (Dahly et al., 2018).

In regard to study design, there were some studies that completed an intervention program and found differences in infant body composition (Clapp & Capeless, 1990; Trak-Fellermeier et al., 2019; van Poppel et al., 2019) while others have not (Clapp et al., 2000; Garnæs et al., 2017; Hopkins et al., 2010). Although a cohort design allows for free-living PA to be reported and/or recorded in addition to sports and exercise leisure-time PA, a randomized control trial that implements an intervention may be able to pinpoint specific PA modifying factors (i.e., duration, frequency, type, intensity) and determine a direct causal relationship between exercise and infant body composition. Due to the lack of consistency across intervention methods it is still difficult to determine the modifying factor/s responsible for the infant body composition differences. With the cohort design of our study, we are not able to directly determine the cause of not observing a trend; however, we speculate that our results may be in line with the findings from the study by Hopkins el al. in that moderate PA during pregnancy may not significantly impact infant body fat percentage composition (Hopkins et al., 2010).

Our methods were similar to the Healthy Start Study (2014) with the exception of our study utilizing an additional PA assessment through an accelerometer (Harrod et al., 2014). Comparing the PPAQ data from the Healthy Start Study (2014) to ours, the women accumulated similar amounts of MET-hours/week during late pregnancy in each category and intensity level. However, our accelerometer data did not reflect the same PA time at higher intensities and during sedentary activities. Currently, no accelerometer cut points have been specifically developed for pregnant women. We speculate that a difference in infant body composition may not have been observed in our study due to the lack of sensitivity of the cut points to PA intensity levels during pregnancy. For example, our accelerometer data suggests none of our participants did vigorous activity, yet, several reported doing things such as running, which would likely be vigorous for a pregnant woman. These inconsistencies force us to scrutinize the way the accelerometer is deciding what is vigorous for a pregnant woman, which may be very different from the general population.

Taken together, these findings are encouraging that PA during pregnancy, at the least, does not appear to have a harmful impact on infant body composition, which is important to demonstrate. However, future research is needed to continue investigating moderate-to-vigorous PA during late pregnancy through objective measures to distinguish a more reliable cut point for pregnancy since the current literature suggests that intensity may be the modifying factor of infant body composition (Bisson et al., 2017; Clapp & Capeless, 1990; Pastorino et al., 2018). Additionally, future studies should consider focusing studies on the recommended threshold of 150 minutes per week of moderate activity (ACOG); this has been an established threshold for other clinical outcomes, but it has not been well-studied in terms of infant body composition.

*Ancillary Findings*

Interestingly, we found women who had a vaginal birth tended to deliver significantly heavier infants with a higher percentage of body fat at birth than those delivered by cesarean section, even when controlling for gestation age at birth. Over the course of vaginal parturition, infants must be able to withstand mechanical forces, transient hypoxia and stress hormone surges for prolonged periods of time (Tribe et al., 2018). Previous literature suggests that infants are able to withstand prolonged periods of hypoxia through circulatory and metabolic adaptations that have yet to be fully elucidated (Newby et al., 2015). During pregnancy, exercise may produce a similar environment to labor over a shorter period of time by temporarily reducing blood flow and improving placental functional capacity (Clapp et al., 2000). Overtime, the increase of the placenta's functional capacity improves nutritional delivery and supports greater fetal growth. We speculate that those mothers who participated in exercise throughout pregnancy may have improved placenta development and therefore, improved overall growth of the infant which could then allow the infant to withstand the stress of a vaginal delivery.

Regarding parity, women who were multiparous tended to deliver infants with a higher percentage of body fat than the infants delivered from nulliparous women. This trend is consistent with the findings from previous studies (Bennett & Kearney, 2020; Joshi et al., 2005). While it appears that infant adiposity increases with parity (Harvey et al., 2007), it is critical to not assume this trend will be observed in consecutive births as maternal physiological factors are independent determinants of infant anthropometrics and potentially differs between consecutive births.

## Strengths and Limitations

A major strength of the study was the use of the new gold standard for infant body composition assessment, air-displacement plethysmography (PEA POD). Utilizing this method in research gives more reliable infant body composition assessment and may be more sensitive to the shifts in infant anthropometrics that have been reported previously. Additionally, utilizing an objective measure of PA (accelerometry) with the self-report questionnaire (PPAQ) allowed for more accurate PA data that is free from potential self-report bias.

Despite the strengths in the present study there were also limitations. Due to the nature of the observational study design, this current study could not determine causal inferences between maternal PA and infant anthropometrics. Likewise, the lack of a cut point for accelerometer data determined for use in pregnancy could be a limitation for our study. Additionally, paternal physical activity and demographic information was not collected during gestation. It could be expected that an infant's outcome will reflect the genetic and environmental exposures that occurred during conception and throughout pregnancy, which in turn could influence adiposity at birth as well as obesity and other related metabolic disease factors later in life.

Another limitation for our study was the population of women surveyed was highly educated (87% of the women surveyed had a college degree or postgraduate degree). Although a significant correlation was not observed between education level and moderate-to-vigorous PA participation, it could be argued that these women have a greater understanding of the health benefits of exercise (i.e., greater health literacy) which may distort their ability to accurately recall and report the duration and/or intensity of activities participated in during late pregnancy (Cutler & Lleras-Muney, 2010). Further, this trend was observed in our results as the women who had achieved a higher education level were more likely to have a greater household income, tend to spend less time sedentary and be more active. Some speculation for this occurrence is that in addition to their potential for greater health literacy than those with a lower education level (Rudd, 2007), a greater household income may afford some women time (i.e., only work one job with set hours) and/or access to resources (i.e., facilities/equipment/programs for PA) which could enable them to be more active.  Due to the women in our population having a higher socio-economic status and greater educational attainment, the results from our study should not be generalized to the broader population.

## Conclusion

Overall, the purpose of this study was to examine the association between physical activity during late pregnancy and infant anthropometric outcomes at birth utilizing the new gold standard method for body composition (PEA POD). The findings from this study suggests that maternal physical activity during late pregnancy does not compromise infant anthropometric outcomes at birth in normal/healthy pregnancies.  Moreover, this study further supports the growing body of literature that maternal physical activity during late pregnancy does not appear to be harmful, and may be beneficial, to infant development.

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APPENDIX A

Study Flyer

# PREGNANT PARTICIPANTS NEEDED


If you or someone you know is pregnant and interested in participating in research, please contact WKU pregnancy studies for more information.

Our lab studies how diet and physical activity influence health in mom and baby- both during pregnancy and during postpartum. We have a variety of studies and would like to find one that works for you!

Eligible participants will receive compensation for their time and effort.

**IF YOU ARE INTERESTED, PLEASE CONTACT US!**

Email: pregnancy@wku.edu

Phone: 270-745-5026 (Dr. Rachel Tinius)

WKU
Exercise Science
School of Kinesiology Recreation & Sport

APPENDIX B

IRB Stamped Informed Consent

WKU

A LEADING AMERICAN UNIVERSITY WITH INTERNATIONAL REACH

SCHOOL OF KINESIOLOGY, RECREATION & SPORT

INSTITUTIONAL REVIEW BOARD WKU APPROVED

**INFORMED CONSENT DOCUMENT**

Project Title: Does physical activity influence metabolic function and inflammation during pregnancy?

Investigator: Dr. Rachel Tinius, School of Kinesiology, Recreation, and Sport, (270) 745-5026

You are being asked to participate in a project conducted through Western Kentucky University. The University requires that you give your signed agreement to participate in this project.

The investigator will explain to you in detail the purpose of the project, the procedures to be used, and the potential benefits and possible risks of participation. You may ask any questions you have to help you understand the project. A basic explanation of the project is written below. Please read this explanation and discuss with the researcher any questions you may have.

If you then decide to participate in the project, please sign this form in the presence of the person who explained the project to you. You should be given a copy of this form to keep.

1. **Nature and Purpose of the Project:**
   Physical activity improves outcomes in pregnant women (irrespective of body weight). However, doctors and scientists do not understand the connections between exercise during pregnancy and infant health. Therefore, the goal of this project is to determine the impact of a physically active lifestyle on infant body composition.

2. **Explanation of Procedures:**
   The study will involve wearing a wristwatch that monitors your physical activity levels for one week. You will also be given a packet of surveys to take inquiring about your exercise and dietary habits.

   Before you are discharged from the hospital after having your baby, the study team will coordinate with you and your nursing team a time to come by and get measurements on the baby. These measurements will include skinfolds at four sites (hip, thigh, arm, and back). You can hold the baby for these measurements. We will also measure the baby's length, head circumference, and abdominal circumference. In addition, we will measure the baby's body composition using a PEAPOD system. This will involve your baby lying naked in an egg-shaped device for 2 minutes. The device is clear and you will be able to

WKU IRB# 16-229
Approval - 12/06/2019
End Date - 12/06/2020
Full Board
Original - 12/14/2015

see and talk to your baby the entire time. There are no risks to your baby by taking these measurements. These measurements may be done bedside or in a separate room by the nursery. Parents are welcome to attend/witness all measurements. A nurse will also be present for measurements.

**Do we have permission to obtain study-related information from your prenatal chart?**

**_____Yes** **_____No**
**Initials** **Initials**

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**3. Discomfort and Risks:**

**<u>What are the risks to you?</u>**

There are no known maternal risks in the present study.

**<u>What are the risks to your baby?</u>**

Skin fold measurements:
There is no risk of harm from this measure, although baby may briefly experience a very mild discomfort resulting from the light pinch of skin with the caliper. This pinching sensation is about as uncomfortable as if you were to lightly take a pinch of skin between your fingers.

PeaPod Measurement: There is no risk to the baby with this measure. However, being naked may upset the baby as they are used to being clothed and swaddled. The machine carefully monitors temperature and will keep them warm during the test.

**4. Benefits:**
You will not benefit directly from being in the study. However, you will learn information about your exercise levels and your baby's body composition. We also hope the knowledge we gain will help us understand lifestyle factors that influence pregnancy outcomes.

You will be paid $35 for your participation in this study. You will be paid $10 when the surveys are collected (and the physical activity monitor has been worn for one week) and $25 when the measurements on your infant are complete.

**5. Confidentiality:**
To help protect your confidentiality, we will do everything we can to keep your information private and protected. Your research file will contain identifiable information such as your name, patient ID#, and birthday. Protected Health Information (PHI) will be created by the study. Study PHI will be kept in your research record and only the research team will have access to the information. The data obtained from this study will be kept confidential. Patients are assigned a study specific identifying number

WKU IRB# 16-229
Approval - 12/06/2019
End Date - 12/06/2020
Full Board
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(PID) upon entry to the study, after which all medical information is referenced by this number. Databases that contain private health, medical or research information are behind firewalls, require password/username for access, are maintained using the PID, and only the PI and Co-PIs, have access to the code that matches the PID with other patient identifiers. All hardcopy data records are stored in locked file cabinets and kept in a locked office. If we write a report or article about this study or share the study data set with others, we will do so in such a way that you cannot be directly identified

**6. Refusal/Withdrawal:**

Refusal to participate in this study will have no effect on any future services you may be entitled to from the University or from your physician. Anyone who agrees to participate in this study is free to withdraw from the study at any time with no penalty.

*You understand also that it is not possible to identify all potential risks in an experimental procedure, and you believe that reasonable safeguards have been taken to minimize both the known and potential but unknown risks.*

Signature of Participant ______________________ Date ____________

Witness ______________________ Date ____________

**Informed Assent from Infants**

My child's participation in this project is voluntary, and I have been told that I may stop his/her participation in this study at any time. I give permission for my baby to participate in this study.

______________________
(Child's name – printed)

______________________ ______________________
(Signature of Parent/Guardian) (Date)

______________________ ______________________
(Name of Parent/Guardian- printed) (Relationship to participant – printed)

THE DATED APPROVAL ON THIS CONSENT FORM INDICATES THAT
THIS PROJECT HAS BEEN REVIEWED AND APPROVED BY
THE WESTERN KENTUCKY UNIVERSITY INSTITUTIONAL REVIEW BOARD
Robin Pyles, Human Protections Administrator
TELEPHONE: (270) 745-3360

INSTITUTIONAL REVIEW BOARD WKU APPROVED

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Full Board
Original - 12/14/2015

# APPENDIX C

## Physician Release Form

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**PHYSICIAN'S RELEASE**

Patient's Name ______________________

This page will give you the information you will need to understand why this study is being done and why your patient is being invited to participate. It will also describe any known risks, inconveniences or discomforts that your patient may have while participating. We encourage you to ask questions at any time, including via email or phone.

1. PURPOSE AND BACKGROUND
   The purpose of this study is to assess the role of exercise during pregnancy on infant body composition.

2. PROCEDURES
   The patient will wear a physical activity monitor for a week and complete surveys related to diet and exercise habits. The infant will be measured via the "PeaPod" system ~24 hours after delivery.

3. RISKS
   There are no known risks to participation.

4. BENEFITS
   The patient will be compensated for her time and effort. There are no direct benefits to the patient, but we believe the knowledge we gain will improve help identify mechanisms to target with future interventions, and thus, improve pregnancy-related outcomes for future women and their infants.

➢ QUESTIONS
If you have any questions or concerns about your patient's participation in this program, please call Dr. Rachel Tinius at 270-745-5026. rachel.tinius@wku.edu

**Physician's Signature**______________________________________ **Date** ___________

**Printed name** ______________________________________________

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APPENDIX D

General Demographic Survey

General Survey Questions

1. Are you currently pregnant? What is your due date?
   YES Due date: ___________ NO
2. Do you have any other children?
   YES how many? _______ ages?_____________ NO
3. What is your age? ________
4. What ethnicity do you associate with?
   a. White
   b. African American
   c. Hispanic
   d. Native American
   e. Asian
   f. Prefer not to say
5. What is the highest level of education completed?
   a. Some high school
   b. High school graduate
   c. Some college
   d. Technical/trade/vocational training
   e. College graduate
   f. Post graduate degree
6. In a typical week, with a workout lasting at least 30 minutes to an hour, how are you currently exercising?
   a. None
   b. Once a week
   c. 2-3 times a week
   d. 4-5 times a week
   e. Everyday
7. Do you have any current/ongoing health issues?
   YES NO
   If yes, please describe below.

   ______________________________________________________________

8. Pre-pregnancy Height _________

9. Pre-pregnancy Weight _________

10. What is your household income? $_____________

APPENDIX E

Pregnancy Physical Activity Questionnaire (PPAQ)

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UMASS

## Pregnancy Physical Activity Questionnaire

**Instructions:**
***Please use an ordinary No. 2 pencil.*** *Fill in the circles completely. The Question will be read by a machine so if you need to change your answer, erase the incorrect mark* ***completely***. *If you have comments, please write them on the back of the questionnaire.*

**Example:** During this trimester, when you are NOT at work, how much time do you usually spend:

E1. **Taking care of an older adult**

*If you take care of your mom for 2 hours each day, then your answer should look like this...* →

- ○ None
- ○ Less than 1/2 hour per day
- ○ 1/2 to almost 1 hour per day
- ○ 1 to almost 2 hours per day
- ● 2 to almost 3 hours per day
- ○ 3 or more hours per day

It is very important you tell us about yourself honestly. There are no right or wrong answers. We just want to know about the things you are doing during this trimester.

1. Today's Date: [ ][ ] / [ ][ ] / [ ][ ][ ][ ] (Month / Day / Year)
2. What was the first day of your last period? [ ][ ] / [ ][ ] / [ ][ ][ ][ ] (Month / Day / Year) ○ I don't know
3. When is your baby due? [ ][ ] / [ ][ ] / [ ][ ][ ][ ] (Month / Day / Year) ○ I don't know

---

During this trimester, when you are NOT at work, how much time do you usually spend:

4. **Preparing meals (cook, set table, wash dishes)**
   - ○ None
   - ○ Less than 1/2 hour per day
   - ○ 1/2 to almost 1 hour per day
   - ○ 1 to almost 2 hours per day
   - ○ 2 to almost 3 hours per day
   - ○ 3 or more hours per day

5. **Dressing, bathing, feeding children while you are <u>sitting</u>**
   - ○ None
   - ○ Less than 1/2 hour per day
   - ○ 1/2 to almost 1 hour per day
   - ○ 1 to almost 2 hours per day
   - ○ 2 to almost 3 hours per day
   - ○ 3 or more hours per day

Page 1

**During this trimester, when you are NOT at work, how much time do you usually spend:**

6. **Dressing, bathing, feeding children while you are <u>standing</u>**
   - O None
   - O Less than 1/2 hour per day
   - O 1/2 to almost 1 hour per day
   - O 1 to almost 2 hours per day
   - O 2 to almost 3 hours per day
   - O 3 or more hours per day

7. **Playing with children while you are <u>sitting or standing</u>**
   - O None
   - O Less than 1/2 hour per day
   - O 1/2 to almost 1 hour per day
   - O 1 to almost 2 hours per day
   - O 2 to almost 3 hours per day
   - O 3 or more hours per day

8. **Playing with children while you are <u>walking or running</u>**
   - O None
   - O Less than 1/2 hour per day
   - O 1/2 to almost 1 hour per day
   - O 1 to almost 2 hours per day
   - O 2 to almost 3 hours per day
   - O 3 or more hours per day

9. **Carrying children**
   - O None
   - O Less than 1/2 hour per day
   - O 1/2 to almost 1 hour per day
   - O 1 to almost 2 hours per day
   - O 2 to almost 3 hours per day
   - O 3 or more hours per day

10. **Taking care of an older adult**
    - O None
    - O Less than 1/2 hour per day
    - O 1/2 to almost 1 hour per day
    - O 1 to almost 2 hours per day
    - O 2 to almost 3 hours per day
    - O 3 or more hours per day

11. **Sitting and using a computer or writing, while <u>not</u> at work**
    - O None
    - O Less than 1/2 hour per day
    - O 1/2 to almost 1 hour per day
    - O 1 to almost 2 hours per day
    - O 2 to almost 3 hours per day
    - O 3 or more hours per day

12. **Watching TV or a video**
    - O None
    - O Less than 1/2 hour per day
    - O 1/2 to almost 2 hours per day
    - O 2 to almost 4 hours per day
    - O 4 to almost 6 hours per day
    - O 6 or more hours per day

13. **Sitting and reading, talking, or on the phone, while <u>not</u> at work**
    - O None
    - O Less than 1/2 hour per day
    - O 1/2 to almost 2 hours per day
    - O 2 to almost 4 hours per day
    - O 4 to almost 6 hours per day
    - O 6 or more hours per day

14. **Playing with pets**
    - O None
    - O Less than 1/2 hour per day
    - O 1/2 to almost 1 hour per day
    - O 1 to almost 2 hours per day
    - O 2 to almost 3 hours per day
    - O 3 or more hours per day

15. **Light cleaning (make beds, laundry, iron, put things away)**
    - O None
    - O Less than 1/2 hour per day
    - O 1/2 to almost 1 hour per day
    - O 1 to almost 2 hours per day
    - O 2 to almost 3 hours per day
    - O 3 or more hours per day

16. **Shopping (for food, clothes, or other items)**
    - O None
    - O Less than 1/2 hour per day
    - O 1/2 to almost 1 hour per day
    - O 1 to almost 2 hours per day
    - O 2 to almost 3 hours per day
    - O 3 or more hours per day

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During this trimester, when you are NOT at work, how much time do you usually spend:

17. **Heavier cleaning (vacuum, mop, sweep, wash windows)**

- O None
- O Less than 1/2 hour per week
- O 1/2 to almost 1 hour per week
- O 1 to almost 2 hours per week
- O 2 to almost 3 hours per week
- O 3 or more hours per week

18. **Mowing lawn while on a riding mower**

- O None
- O Less than 1/2 hour per week
- O 1/2 to almost 1 hour per week
- O 1 to almost 2 hours per week
- O 2 to almost 3 hours per week
- O 3 or more hours per week

19. **Mowing lawn using a walking mower, raking, gardening**

- O None
- O Less than 1/2 hour per week
- O 1/2 to almost 1 hour per week
- O 1 to almost 2 hours per week
- O 2 to almost 3 hours per week
- O 3 or more hours per week

## Going Places...

**During this trimester, how much time do you usually spend:**

20. **Walking slowly to go places (such as to the bus, work, visiting)** ***Not for fun or exercise***

- O None
- O Less than 1/2 hour per day
- O 1/2 to almost 1 hour per day
- O 1 to almost 2 hours per day
- O 2 to almost 3 hours per day
- O 3 or more hours per day

21. **Walking quickly to go places (such as to the bus, work, or school)** ***Not for fun or exercise***

- O None
- O Less than 1/2 hour per day
- O 1/2 to almost 1 hour per day
- O 1 to almost 2 hours per day
- O 2 to almost 3 hours per day
- O 3 or more hours per day

22. **Driving or riding in a car or bus**

- O None
- O Less than 1/2 hour per day
- O 1/2 to almost 1 hour per day
- O 1 to almost 2 hours per day
- O 2 to almost 3 hours per day
- O 3 or more hours per day

## For Fun or Exercise...

**During this trimester, how much time do you usually spend:**

23. **Walking slowly for fun or exercise**

- O None
- O Less than 1/2 hour per week
- O 1/2 to almost 1 hour per week
- O 1 to almost 2 hours per week
- O 2 to almost 3 hours per week
- O 3 or more hours per week

24. **Walking more quickly for fun or exercise**

- O None
- O Less than 1/2 hour per week
- O 1/2 to almost 1 hour per week
- O 1 to almost 2 hours per week
- O 2 to almost 3 hours per week
- O 3 or more hours per week

25. **Walking quickly up hills for fun or exercise**

- O None
- O Less than 1/2 hour per week
- O 1/2 to almost 1 hour per week
- O 1 to almost 2 hours per week
- O 2 to almost 3 hours per week
- O 3 or more hours per week

**During this trimester, how much time do you usually spend:**

26. **Jogging**
   - ○ None
   - ○ Less than 1/2 hour per week
   - ○ 1/2 to almost 1 hour per week
   - ○ 1 to almost 2 hours per week
   - ○ 2 to almost 3 hours per week
   - ○ 3 or more hours per week

27. **Prenatal exercise class**
   - ○ None
   - ○ Less than 1/2 hour per week
   - ○ 1/2 to almost 1 hour per week
   - ○ 1 to almost 2 hours per week
   - ○ 2 to almost 3 hours per week
   - ○ 3 or more hours per week

28. **Swimming**
   - ○ None
   - ○ Less than 1/2 hour per week
   - ○ 1/2 to almost 1 hour per week
   - ○ 1 to almost 2 hours per week
   - ○ 2 to almost 3 hours per week
   - ○ 3 or more hours per week

29. **Dancing**
   - ○ None
   - ○ Less than 1/2 hour per week
   - ○ 1/2 to almost 1 hour per week
   - ○ 1 to almost 2 hours per week
   - ○ 2 to almost 3 hours per week
   - ○ 3 or more hours per week

**Doing other things for fun or exercise? Please tell us what they are.**

30. ______________ Name of Activity
   - ○ None
   - ○ Less than 1/2 hour per week
   - ○ 1/2 to almost 1 hour per week
   - ○ 1 to almost 2 hours per week
   - ○ 2 to almost 3 hours per week
   - ○ 3 or more hours per week

31. ______________ Name of Activity
   - ○ None
   - ○ Less than 1/2 hour per week
   - ○ 1/2 to almost 1 hour per week
   - ○ 1 to almost 2 hours per week
   - ○ 2 to almost 3 hours per week
   - ○ 3 or more hours per week

---

Please fill out the next section if you work for wages, as a volunteer, or if you are a student. If you are a homemaker, out of work, or unable to work, you do not need to complete this last section.

## At Work...

**During this trimester, how much time do you usually spend:**

32. **Sitting at working or in class**

   - ○ None
   - ○ Less than 1/2 hours per day
   - ○ 1/2 to almost 2 hours per day
   - ○ 2 to almost 4 hours per day
   - ○ 4 to almost 6 hours per day
   - ○ 6 or more hours per day

33. **Standing or slowly walking at work while carrying things (heavier than a 1 gallon milk jug)**
   - ○ None
   - ○ Less than 1/2 hour per day
   - ○ 1/2 to almost 2 hours per day
   - ○ 2 to almost 4 hours per day
   - ○ 4 to almost 6 hours per day
   - ○ 6 or more hours per day

34. **Standing or <u>slowly</u> walking at work <u>not</u> carrying anything**
   - ○ None
   - ○ Less than 1/2 hours per day
   - ○ 1/2 to almost 2 hours per day
   - ○ 2 to almost 4 hours per day
   - ○ 4 to almost 6 hours per day
   - ○ 6 or more hours per day

35. **Walking <u>quickly</u> at work while <u>carrying</u> things (heavier than a 1 gallon milk jug)**
   - ○ None
   - ○ Less than 1/2 hour per day
   - ○ 1/2 to almost 2 hours per day
   - ○ 2 to almost 4 hours per day
   - ○ 4 to almost 6 hours per day
   - ○ 6 or more hours per day

36. **Walking <u>quickly</u> at work <u>not</u> carrying anything**
   - ○ None
   - ○ Less than 1/2 hour per day
   - ○ 1/2 to almost 2 hours per day
   - ○ 2 to almost 4 hours per day
   - ○ 4 to almost 6 hours per day
   - ○ 6 or more hours per day

**Thank You**

APPENDIX F

Infant Visit Protocol

## Infant Visit Protocol

1. Mother Contacts WKU Pregnancy Research Team
    - 1.1. Baby is delivered in *Labor and Delivery Ward at The Medical Center*
    - 1.2. Mom and baby transferred to the *Postpartum Ward (2B) at The Medical Center*
    - 1.3. Mother notifies WKU Pregnancy Research Team (pregnancy@wku.edu) of birth
    - 1.4. WKU Research Team arranges for study visit-scheduled before discharge
2. Research Team Contacts Hospital
    - 2.1. WKU Research Team Member contacts nurses station in the *Postpartum Ward (2B) at The Medical Center* to notify of upcoming study visit *(270)-796-2398*
    - 2.2. Postpartum nurse/aid turns on the PEAPOD TWO to FOUR HOURS before research team member arrives to calibrate
3. WKU Research Team Member Arrives at Hospital
    - 3.1. Team Member arrives at hospital ~45 minutes before study visit
    - 3.2. Team Member enters *The Medical Center* at the *main hospital entrance*
    - 3.3. Team Member requests entrance to *Postpartum Ward (2B)* from nurses station (nurse contacted from previous phone call is referenced)
    - 3.4. Upon entrance to the *Postpartum Ward (2B)*, Team Member sanitizes hands at nurses station
    - 3.5. Team Member requests nurse/aid assistance for access to the PEAPOD in the *2B Overflow Supply Closet* located on 2A
4. Calibrate PEAPOD
    - 4.1. Upon entrance to *Supply Closet*, a safe and clear path to the PEAPOD is created
        - 4.1.1. All excess nursery beds, isolates, and equipment in storage that are blocking a clear, direct path from the PEAPOD to the door are repositioned within the closet
    - 4.2. Team Member wakes PEAPOD from sleep mode and signs in to the COSMED software on the PEAPOD

      [redacted]
    - 4.3. Team Member ensures PEAPOD is warm enough before calibration begins
        - 4.3.1. Reference Chamber (88.9°F)
        - 4.3.2. Test (88.9°-89.7°F)
        - 4.3.3. Heater (closer to the reference chamber (88.9°F) the better; needs to be lower than (90.1°F) to shut off the TOO COLD ALERT)
            - **4.3.3.1. PEAPOD cannot be calibrated if the reference & test chambers are below 86°F, heater is above 97°F; and the TOO COLD ALERT is present**
    - **4.4. Select QC Tab to begin Calibration**
        - **4.4.1. Analyze Hardware**
            - 4.4.1.1. Follow all prompts on the screen to ensure all hardware is operating properly before proceeding
            - 4.4.1.2. If any error message appears (1: reference PEAPOD user manual below keyboard of PEAPOD in white 3-ring binder. 2: notify *Dr. Rachel*

*Tinius* (270)-745-5026 of hardware malfunction. 3: call COSMED representative to assist with troubleshooting)

4.4.1.3. Must have OPERATIONAL or PASS status before proceeding

**4.4.2. Calibrate Scale**

4.4.2.1. Scale should be calibrated before each study visit

4.4.2.2. Follow all prompts using the 2kg calibrated & verified weight on the scale, make sure to place in the center

4.4.2.3. Must **PASS** before moving on

4.4.2.4. If it **FAILS**, repeat scale calibration again

4.4.2.5. If it **FAILS** more than twice, contact Dr. Rachel Tinius and COSMED Rep

**4.4.3. SKIP ~~Check Scale~~**

**4.4.4. Autorun**

4.4.4.1. Follow all prompts using the calibrated & verified Volume Cylinder; make sure cylinder rests in the crevice within the testing chamber to ensure it does not move while closing the chamber

4.4.4.2. Must **PASS** before moving on

4.4.4.3. If it **FAILS**, repeat Autorun again

4.4.4.4. If it **FAILS** more than twice, contact Dr. Rachel Tinius and COSMED Rep

**4.4.5. Volume**

4.4.5.1. Follow all prompts using the calibrated & verified Volume Cylinder; make sure cylinder rests in the crevice within the testing chamber to ensure it does not move while closing the chamber

4.4.5.2. Must **PASS** before moving on

4.4.5.3. If it **FAILS**, repeat Volume test again

4.4.5.4. If it **FAILS** more than twice, contact Dr. Rachel Tinius and COSMED Rep

**4.4.6. Closing**

4.4.6.1. Logout of COSMED Software

4.4.6.2. Shut down the PEAPOD like a computer (i.e., start--shutdown)

4.4.6.3. Ensure machine is completely off before unplugging from the wall

5. Unlock and remove yellow plastic chain from around PEAPOD
6. Gather baby bag, study folder, 2x *Chux* (i.e., blue sanitary pads used during study visit located in the clear, plastic tote to the right of the PEAPOD on the floor of the supply closet), and baby sock cap (also located in the clear, plastic tote to the right of the PEAPOD on the floor of the supply closet)
7. Unlock wheels of PEAPOD and move to 2B
8. Team Member requests nurse/aid assistance *(270)-796-2398* for access back over to 2B with the PEAPOD for study visit in participant's room
9. Locate, knock, verify study visit time, and enter participant's room
10. Set up PEAPOD in room

10.1. Plug in, position PEAPOD so back faces the door, lock wheels

10.2. Team Member sanitizes hands

10.3. Team Member signs in to the COSMED software on the PEAPOD

[redacted]

10.3.2. Make sure PEAPOD begins sequence to warm back up and prepare for test

**11. Infant Measures**

11.1. Mother orally responds to infant birth demographic questions and is recorded by research team member on the *Baby Measurements sheet* in the study folder

11.2. Team Member washes hands in participant's room and gloves up before infant measurements begin

11.3. Take out the *Gullick Tape Measure* and follow circumference protocol (Johnson and Engstrom 2002)

11.3.1. Remove any head covering and measure head circumference—record in cm in study folder

11.3.2. Remove blanket and clothing (i.e., onesie) measure abdominal circumference—record in cm in study folder

11.4. Skinfolds

11.4.1. Folds of the skin at four sites-triceps, subscapular, thigh, and hip-measured by lifting the skin with the thumb and index finger and the thickness of each fold is pressed with a caliper (Harpenden Skinfolds Caliper, Baty International, United Kingdom) twice and recorded in mm in the study folder. If there is a difference greater than 2mm between two measurements, a third measure is taken.

11.5. PEAPOD

11.5.1. Select TEST--BODY COMPOSITION on PEAPOD

11.5.2. Input infant birth demographic data into PEAPOD

11.5.3. Place one blue Chux(calibration) & the calibration infant bracelets on the scale to briefly tare the scale

11.5.4. Make sure infant is completely undressed, wrap the infant with the other blue Chux(testing), remove calibration materials and lie infant on scale

11.5.5. Place calibration bracelets and Chux(calibration) back on briefly to tare the scale

11.5.6. Place the baby sock cap on the infant's head so that all hair is stuck down smoothly against the head

11.5.7. Infant is then placed in the testing chamber of the PEAPOD without the blue chux

11.5.8. Body composition test takes approx. 90 seconds

11.5.9. Infant is then removed from testing chamber and redressed by parent/support visitor or the research team member assists upon the parent's request

11.6. Wrap-up

11.6.1. Mother is paid for the infant visit and signs the payment signature/release form in the study folder

11.6.2. PEAPOD print off reviewed and copy is given to parent

11.6.3. WKU Research Participant baby cap given as thank you

11.6.3.1. Make sure to inform parent that it has not been washed yet

12. Clean

12.1. Remove a Clorox wipe from container in baby bag and wipe thoroughly the tape measure, skinfold calipers, and all surfaces of the PEAPOD (i.e., scale, testing chamber & shield, handle on outside of testing chamber, handle on back of PEAPOD, and keyboard)

13. Shutdown PEAPOD
    - 13.1. Ensure measurement report has printed two copies (one for participant and one placed in study folder)
    - 13.2. Hit FINISH TEST
    - 13.3. Logout of COSMED Software
    - 13.4. Shut down the PEAPOD like a computer (i.e., start--shutdown)
    - 13.5. Ensure machine is completely off before unplugging from the wall
14. Team Member requests nurse/aid assistance *(270)-796-2398* for access back over to 2A with the PEAPOD
    - 14.1. Transport PEAPOD back to the *2B Overflow Supply Closet* located on 2A
15. Place PEAPOD with back facing wall, plug in, lock wheels, and reposition yellow chain and lock in place