OREGON HEALTH & SCIENCE UNIVERSITY
SCHOOL OF MEDICINE – GRADUATE STUDIES

PHYSICAL ACTIVITY, MATERNAL WEIGHT GAIN, AND POSTPARTUM WEIGHT RETENTION OF PARTICIPANTS IN THE OHSU PREGNANCY, EXERCISE, AND NUTRITION STUDY

By

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LIST OF ABBREVIATIONS

ACOG	American College of Obstetrics & Gynecology
BMI	Body Mass Index
BMR	Basal Metabolic Rate
CDC	Center for Disease Control
cpm	Counts Per Minute
C-Section	Cesarean Section
GDM	Gestational Diabetes Mellitus
IOM	Institute of Medicine
LGA	Large for Gestational Age
MET	Metabolic Equivalents of Task
MVPA	Moderate-to-Vigorous Physical Activity
OHSU	Oregon Health & Science University
PEN	Pregnancy, Exercise, & Nutrition Study
PA	Physical Activity
WHO	World Health Organization

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ABSTRACT

Background

Moderate-to-vigorous physical activity (MVPA) of ≥ 30 minutes/day at least 4 days/week is recommended during pregnancy to promote appropriate gestational weight gain (GWG). Only about 15% of all women in the United States meet this recommendation during pregnancy. Weight gain during pregnancy and return to pre-pregnancy weight are important predictors of maternal and fetal health outcomes.

Methods

Physical activity (PA) was measured in 28 pregnant women using Actigraph accelerometers worn on the right hip during waking hours for 7 consecutive days each trimester and at three-months postpartum. Wear-time compliance was defined as ≥ 6 hours/day for ≥ 4 days in each 7-day period. Women were characterized as normal weight (NW) or overweight (OW) based on pre-pregnancy BMI, and as meeting or exceeding GWG recommendations. Odds ratios and t-tests were used to estimate the relationships between pre-pregnancy weight status and PA level and PA level and GWG.

Results

MVPA declined with duration of gestation, NW women spent 43 ± 19 (5.7%), 33 ± 17 (4.2%), and 30 ± 20 (3.8%) minutes/day performing MVPA during the first, second, and third trimester, respectively; OW women spent 26 ± 14 (3.3%), 22 ± 14 (2.9%), and 20 ± 15 (2.5%) minutes/day performing MVPA during the first, second, and third trimester, respectively. Percent time performing MVPA was significantly lower in OW than NW women during the first trimester (62%, CI:41.7-92.5%, p=0.02). During the first trimester, NW woman were 6.0 times (CI:1.11-32.6, p=0.03) more likely to meet PA recommendations than OW women. Women who met PA recommendations during any trimester of pregnancy were not more likely to meet GWG recommendations than those who did not. At three-months postpartum, of total accelerometer wear-time, NW women spent 3.7% performing MVPA; OW women spent 1.9% performing MVPA. Women who performed more minutes/day of MVPA did not lose more weight (as a % of weight gain during pregnancy) at three-months postpartum, regardless of pre-pregnancy weight status.

Conclusions

Women who met the PA recommendation were not more likely to gain appropriate weight or lose more weight by three-months postpartum. However, because of our small sample size, this conclusion needs to be interpreted with caution. Instead, we support the recommendation to design, implement and test more effective interventions to increase PA during pregnancy and postpartum to support healthy maternal and infant outcomes in both the short- and long-term.

CHAPTER 1 INTRODUCTION

Significance

Regular physical activity helps to alleviate many of the common discomforts and complications during pregnancy. Physical activity throughout pregnancy is associated with improved circulation, sleep, and mood; increased energy; reduced back pain, constipation, cramps, and swelling; and may also ease the labor and delivery process (1-5). In the absence of medical or obstetric complications, women with single gestation pregnancies are encouraged to follow the same guidelines for exercise as non-pregnant women, established by the Centers for Disease Control and Prevention and the American College of Sports Medicine. These guidelines suggest an accumulation of 30 minutes or more of moderate exercise on most, if not all, days of the week (or at least 150 minutes per week) (1). Currently only about 15% of pregnant women exercise at the recommended levels, which is significantly lower than the 45% of the general population who meet the goal (2, 3, 6).

The type, duration, and intensity of exercise during pregnancy necessary to improve maternal and fetal outcomes have not been well defined. Women who continue a regular routine of strength training and aerobic exercise for the duration of pregnancy have increased maternal (and perhaps fetal) plasma volume, intervillous space blood volume, cardiac output and placental function (3, 7, 8). These changes may increase 24-hour oxygen and nutrient delivery to the placenta and thus protect the fetus from reductions in oxygen and nutrient delivery during exercise (9-12). Additionally, participating in physical activity throughout pregnancy increases insulin sensitivity and modulates maternal blood glucose concentration, thus reducing the risk for developing gestational diabetes mellitus (GDM) as well as limiting the associated complications of GDM (13-16). Pregnant women, who are sedentary, and those who participate in less than 30 minutes of moderate to vigorous physical activity per day, are four times more likely to have a cesarean delivery, to have abdominal and/or vaginal operations during delivery, and to have longer duration of labor compared to women who exercised regularly (13, 17-20).

One in five American women are obese at the start of pregnancy, about 50% of women who are overweight gain more than 30 pounds during pregnancy, and two out of three women exceed the Institutes of Medicine (IOM) recommendations for gestational weight gain (21). Between 1% and 18% of all pregnant women will be diagnosed with GDM and this number is increasing every year (14, 21). At six months postpartum, about 50% of women retain more than 10 pounds, and 25% retain more than 20 pounds of weight gained during pregnancy (21). Mothers who are overweight or obese when they conceive are more likely to have children who become overweight or obese and these children are more likely to be overweight or obese as adults (21). There is increasing evidence that enhanced dietary and physical activity practices could effectively reduce these outcomes (5, 22).

Overall fetal well-being does not appear to be compromised after short-duration vigorous activity (below 90% maximal maternal heart rate), and it is known that moderate physical activity during pregnancy leads to positive outcomes for both the mother and her child (3, 7, 10, 23). However, there is inconsistency in the recommendations for type, duration, and intensity of physical activity that pregnant woman engage in throughout pregnancy. Overall, the evidence indicates that exercise during pregnancy is safe and perhaps even reduces the risk of preeclampsia and gestational diabetes (2, 3). Unfortunately, much of the research examining exercise during pregnancy is observational, and the few randomized controlled trials that have been published are small and inadequately powered. To address these limitations, we propose to analyze data from the OHSU Pregnancy, Exercise, & Nutrition (PEN) study to determine if physical activity impacts weight gain and weight retention postpartum.

Study Aims

The aims of this analysis were to:

1. Describe patterns of daily physical activity, as measured by accelerometers, among participants in the Pregnancy Exercise & Nutrition (PEN) feasibility study during the first, second, and third trimesters of pregnancy, at 3 months postpartum, and overall.
2. Compare the amount of physical activity performed by overweight/obese (BMI ≥ 25 kg/m^2) and normal weight (BMI 18.9 - 25 kg/m^2) women, during the first, second, and third trimesters of pregnancy, at 3 months postpartum, and overall.

We hypothesized that the amount of time spent in moderate to vigorous physical activity (MVPA) would be different between normal weight and overweight/obese women at each time point, and overall.

3. Evaluate the relationship between physical activity and maternal gestational weight gain and maternal weight retention at three-months postpartum.

a. We hypothesized that women who meet the physical activity recommendation of 30 minutes of MVPA per day at least 4 days per week during the first, second, and third trimesters, and overall would be more likely to meet the IOM recommendations for weight gain during pregnancy (indexed to week of gestation age at delivery) than those who did not meet the physical activity recommendation.
b. We hypothesized that at three-months postpartum mean maternal weight, as a percent of self-reported pre-pregnancy weight, would be lower among women who met the physical activity recommendation of 30 minutes a day at least 4 days a week during each trimester of pregnancy than those who did not meet the recommendation during any one or all three trimesters of pregnancy.
c. We hypothesized that at three-months postpartum maternal weight, as a percent of self-reported pre-pregnancy weight, would be lower among women who met the physical activity recommendation of 30 minutes a day at least 4 days a week at 3 months postpartum than those who did not meet the recommendation.

CHAPTER 2 REVIEW OF THE LITERATURE

Physical Activity Recommendations During Pregnancy

Physical activity is beneficial for women during pregnancy and in the postpartum period; in most cases it is not associated with risks for the developing fetus or newborn and can lead to changes in lifestyle that can have long-term benefits for both the mother and her baby (4, 24). Physical activity during pregnancy may be associated with reduced rates of preeclampsia, gestational diabetes, cesarean sections, low back pain, anxiety, nausea, heartburn, insomnia, leg cramps and possibly excessive weight gain (2, 3).

In a 2014 opinion paper, The Academy of Nutrition and Dietetics wrote, "physical activity during pregnancy benefits a woman's overall health. In a low-risk pregnancy, moderately intense activity does not increase risk of low birth weight (LBW) preterm delivery or miscarriage. Recreational moderate and vigorous physical activity during pregnancy is associated with a 48% lower risk of hyperglycemia, specifically among women with pre-pregnancy BMI >25 kg/m^2. A prenatal nutrition and exercise program, regardless of exercise intensity, has been shown to reduce excessive gestational weight gain and decrease weight retention at 2 months postpartum in women of normal pre-pregnancy BMI" (25).

Extensive research has shown that participating in moderate-intensity aerobic physical activity during pregnancy encourages a healthy lifestyle and produces a myriad of positive health benefits for both the mother and fetus. According to the 2008 *Physical Activity Guidelines for Americans* aimed at improving health and well-being of all people, experts recommended that non-pregnant individuals participate in at least 30 minutes of moderate exercise per day on most, if not all days of the week (1). The Centers for Disease Control (CDC) recommend that all adults should achieve at least 150 minutes per week of moderate-intensity aerobic physical activity, and this recommendation also stands for healthy women during pregnancy (26).

Currently only 15% of women engage in the recommended amount of physical activity during pregnancy (2). Reasons for the low rate of physical activity among pregnant women likely include the common perception that physical activity during pregnancy is risky. Such concerns among the lay public have been reinforced by practitioners who have a history of discouraging women from engaging in physical activity, perhaps due to their own perceptions of increased risks of miscarriage, preterm labor, low infant birth rate, and other complications (2).

Physical activity recommendations are based on current guidelines that indicate moderate-intensity, low-impact, aerobic exercise should be done on most, if not all days of the week (1). New guidelines have been proposed that would increase weekly physical-activity recommendations, incorporate more vigorous intensity physical activity, and add light strength training to the routine of healthy pregnant women (24). However, these recommendations have not yet been universally accepted and previous epidemiological research suggests that about half of all women (~50-60%) do not participate in regular physical activity during pregnancy (27-29).

American College of Obstetrics and Gynecology Recommendations

Previous recommendations from the American College of Obstetricians and Gynecologists (ACOG) published in 1985 stated that active pregnant women should stringently limit the type, duration, and intensity of their exercise to minimize both fetal and maternal risk (23). In 1994, the ACOG modified these recommendations to state that "during pregnancy, women can continue to exercise and derive health benefits even from mild to moderate exercise routines. Regular exercise (at least three times per week) is preferable to intermittent activity". However, the guidelines did not include any recommendations for inactive women (23). The most recent ACOG recommendations published in 2002 state that pregnant women without contraindications should exercise, and women who were inactive prior to becoming pregnant can start an exercise program. However, despite updated recommendations encouraging women to be physically active, pregnant women have been slow to engage and many physicians have been slow to deliver these recommendations (1, 30).

Appropriate and Safe Types of Physical Activity During Pregnancy

Historically, women were advised to reduce physical activity levels during pregnancy. This advice was based on concerns that physical activity would negatively affect pregnancy outcomes by raising core body temperature, by increasing the risk of maternal musculoskeletal injury due to changes in posture and ligamentous laxity, and by shunting the transport of oxygen and nutrients to maternal skeletal muscle rather than to the developing fetus (31).

Starting an exercise regime before or early in pregnancy has been shown to have the greatest impact on maternal and fetal health outcomes. Notably, physical activity has been shown to have a positive effect on fetoplacental growth rate, improving placental functional capacity, which increases nutrient delivery to the fetus and ultimately size at birth; (32). Physical activity should be performed at around 60-70% of the maximum heart rate, which is variable depending on age and/or activity level before pregnancy. A safe range of heart rate that may occur while performing aerobic physical activity during pregnancy is generally 135-155 beats per minute. Women who were inactive before pregnancy and begin physical exercise during pregnancy should start aerobic activity with a warm-up, beginning with 15 minutes of effort three times per week and slowly prolonging effort to 30 minutes four times per week (1).

A number of different aerobic, anaerobic, stretching and strength training activities have been identified as safe and beneficial throughout pregnancy. The safest and most productive aerobic activities are swimming, brisk walking, indoor stationary bicycling and low-impact aerobics. Strength training activities approved during pregnancy include yoga, stretching, calisthenics, stomach-strengthening exercises, pelvic tilt exercises, and pelvic floor exercises (33-35). However, Bikram style yoga ("hot yoga"), conducted in rooms over 90 degrees Fahrenheit is not advised and could be harmful to the mother and fetus during pregnancy (36).

Emerging research on yoga during pregnancy is associated with positive outcomes particularly for decreasing labor pain, increasing maternal comfort, and increasing birth outcome scores (37, 38). Additionally gentle strength training yoga has been shown to improve sleep, reduce stress and anxiety, and increase strength, flexibility and endurance of muscles needed for childbirth (36-38).

Contact sports should be avoided during pregnancy due to possible abdominal trauma, jarring motions and rapid changes in direction. Exercises that require women to lie on their back or right side for more than three minutes should be avoided after the first trimester because it leads to a lower cardiac output and symptomatic arterial hypotension due to pressure on the wall of the inferior vena cava vein (39). Pregnant women should avoid performing physical exercises at an altitude of over 2,500 meters (about 8,200 feet) above sea level, without a period of 4-5 days adaptation to these conditions. Intensive physical activity at this altitude may result in decreased blood flow to the uterine muscle, decreased maternal placental blood flow, and consequently increased risk of oxygen deficiency in the fetus (34, 40).

During the postpartum period women should begin physical activity of a moderate intensity (1). If the course of pregnancy and delivery were normal, the woman may start physical activity immediately, in the form of walks, pelvic exercises or stretching (41). After a cesarean section, moderate physical activity may be started 6-8 weeks after delivery and after consulting her health care provider (35).

Physiological Changes During Normal Pregnancy

Early in pregnancy, increases in estrogen, progesterone, and other hormone and substrate production, first from the corpus luteum and then from the placenta, lead to significant changes in maternal anatomy and physiology (11). These changes occur to meet the metabolic needs of the mother as well as the growing fetus. Maternal support for fetal growth and development includes substrate availability for hormone production and fetal nutrition, transport and exchange of nutrient substrates between mother and fetus, and disposal of wastes, including heat, carbon dioxide, and other metabolic waste products (11).

Basal metabolic rate increases in pregnancy to support the increased demands of pregnancy, as well as an increase in maternal weight. Increased maternal energy demands to support the growing fetus may be as high as 300 kcal/day, particularly in the second and third trimesters (11, 12). During pregnancy, women experience changes in carbohydrate metabolism, characterized by fasting hypoglycemia and postprandial hyperglycemia. Plasma insulin levels increase and the observed state of peripheral insulin resistance in later pregnancy is believed to provide the necessary glucose supply to meet fetal growth needs (11). Metabolic changes favor maternal fat accretion in early pregnancy and lipolysis later in pregnancy.

Blood volume in pregnancy increases by nearly half per term, with a larger increase in plasma compared to red blood cells, resulting in a physiologic reduction in hemoglobin and hematocrit values (11). Systemic vascular resistance decreases during pregnancy, accommodating the increase in blood volume and resulting in a slight decrease in blood pressure, especially during the third trimester. Cardiac output increases in early pregnancy as a result of the decrease in vascular resistance. Resting heart rate also increases, beginning in early pregnancy, by approximately 10 to 15 beats per minute (11, 12).

Consistent with the increase in systemic blood volume, renal blood flow and glomerular filtration increase as much as 50% during pregnancy, beginning in the first trimester. Increased rates of glomerular filtration along with reduced tubular reabsorption of nutrients may result in increased urinary excretion of amino acids, water-soluble vitamins, calcium, and possibly glucose during normal pregnancy (11, 12).

Anatomic changes to the respiratory tract include a rise of approximately 4 cm in the diaphragm and a widening of the subcostal angle of about 2 cm, resulting in a small decrease in residual volume and overall lung capacity of 200 mL but no change in vital capacity. Functional reserve capacity and expiratory reserve volume are also lower by approximately 20-30%. Pulmonary tidal volume, minute volume, and minute oxygen uptake increase throughout pregnancy (11).

In the musculoskeletal system, increased hormone levels of progesterone and relaxin result in softening and relaxation in the joints, resulting in more mobility. As the gravid uterus increases in size, the women's center of gravity shifts and may result in the lower back and anterior flexion in the neck. Decreased venous return in late pregnancy as the uterus increases in size often results in edema of the lower extremities (11).

Effects of Physical Activity on Physiological Changes During Pregnancy

Concern for fetal well-being during exercise in pregnancy relates to having adequate utero-placental blood flow to support fetal oxygen needs as well as adequate glucose and other substrates to support fetal growth and prevent fetal hyperthermia, particularly in the first trimester (12). Normal adaptations in the second half of pregnancy include insulin resistance, which may be improved by physical activity (12).

The body of research available to date supports modest levels of moderate to vigorous physical activity during pregnancy as safe for both mothers and their developing fetuses. Both regular physical activity and the physiological demands of pregnancy increase the need for substrates to support maternal and fetal needs. As a result, it is important that maternal food intake is adequate to support appropriate weight gain and fetal development based on the IOM guidelines.

Contraindications for Engaging in Physical Activity During Pregnancy

Absolute contraindications to aerobic physical activity during pregnancy as described by ACOG include heart disease, hemodynamic instability, restrictive lung disease, incompetent cervix, multiple gestation at risk for premature labor, persistent second- or third- trimester bleeding, placenta previa after 26 weeks of gestation, premature labor during the current pregnancy, ruptured membranes, and preeclampsia/ pregnancy-induced hypertension (1). Relative contraindications as described by ACOG, include severe anemia, unevaluated maternal cardiac arrhythmia, chronic bronchitis, extreme morbid obesity, extreme underweight (BMI < 12 kg/m^2), history of extremely sedentary lifestyle, intrauterine growth restriction, orthopedic limitations, poorly controlled seizure disorder, poorly controlled hyperthyroidism, and heavy smoker (1). Warning signs to terminate exercise while pregnant include vaginal bleeding, dyspnea prior to exertion, dizziness, headache, chest pain, muscle weakness, calf pain or swelling, preterm labor, decreased fetal movement, and/or amniotic fluid leakage (1). While performing physical activity women should consume an adequate amount of calories and limit training sessions to less than 45 minutes, to reduce the risk of exercised-induced hypoglycemia (1). Additionally women should consume an adequate amount of water to maintain fluid balance and avoid dehydration.

Effects of Physical Activity During Pregnancy on Maternal Outcomes

There is evidence to support the link between physical activity during pregnancy and a number of positive maternal outcomes, including reduced rates of preeclampsia, gestational diabetes, excessive weight gain and other concerns.

Preeclampsia

Hypertensive disorders during pregnancy are the second leading cause, after embolism, of maternal mortality in the United States, accounting for approximately 15% of such deaths (1, 42). Hypertension in pregnancy is associated with complications including abruption placentae, cerebral hemorrhage, hepatic failure, and acute renal failure (42). Preeclampsia, one of the hypertensive disorders, occurs in 3 to 4% of pregnancies (42). The association between exercise during pregnancy and reduced risk of preeclampsia is consistent across observational studies. Sorensen et al. found that women who participated in any light or moderate exercise (activities with metabolic equivalents of task <6) were less likely to develop preeclampsia than women who were completely inactive (43). Brisk walking, when compared with no walking at all was associated with a 30% to 33% reduction in preeclampsia risk (43). Marcoux et al. found that leisure time physical activity during the first 20 weeks of pregnancy was associated with a reduced risk of preeclampsia and gestational hypertension (44). In addition, there was an inverse relationship between number of exercise sessions per week and risk of preeclampsia. Relative to inactive women, those who were vigorously active during pregnancy experienced a 54% reduction of risk for preeclampsia, and those who engaged in light or moderate activity experienced a 24% reduction of risk (44).

Gestational Diabetes

Overall the support for impact of physical activity on risk for gestational diabetes is inconsistent. Avery et al. randomized pregnant women with gestational diabetes (n=33) to either an exercise group (2 sessions at the gym and 2 at home) or a control group (45). Participants were instructed to exercise at 70% of their maximum heart rate for 20 minutes, in addition to a 5-minute warm up and a 5-minute cool-down, at both the gym and at home (45). There were no significant differences in fasting blood glucose concentrations between the exercise and non-exercise groups, although the exercise group demonstrated a modest increase in cardiorespiratory fitness relative to the control group (45). Brankston et al. randomly assigned overweight participants with gestational diabetes to diet alone or diet plus resistance training interventions and found no difference regarding the number of women with insulin prescriptions, but women in the exercise arm were prescribed significantly less insulin than those in the diet alone arm. The authors concluded that resistance exercises may help to avoid insulin therapy for some overweight women (46). In a retrospective survey of 12,799 pregnant women, Dye et al. found that physical activity (defined as 1 or more sessions per week) was not associated with lower rates of gestational diabetes for women with a BMI of less than 33 kg/m^2, but it was for women with a BMI greater than 33 kg/m^2 (47).

Some studies indicate support for the protective effect of exercise on gestational diabetes, for example in a prospective cohort study of 909 pregnant women, Dempsey et al. found that compared with inactive women, women who engaged in any physical activity experienced a 56% reduction in gestational diabetes risk, and women who were physically active for more than 4.2 hours per week experienced a 76% reduction in gestational diabetes risk (48). In another prospective cohort study of 1,805 women found that light to moderate physical activity was associated with reduced risk of glucose intolerance and gestational diabetes (16).

Physical Activity during Pregnancy and its Association with Gestational Weight Gain

Results of studies looking at the relationship between physical activity during pregnancy and gestational weight gain show mixed results. The inconsistency across studies could be attributed to several factors, including how the study defined exercise or physical activity, the level of physical activity achieved and maintained by women during their pregnancy, and whether physical activity level was controlled.

Clapp and Little compared women who continued to engage in exercise during pregnancy to those who quit engaging in exercise during pregnancy and found that women in the who did not engage in physical activity had significantly higher gestational weight gain than the exercising women, 13 ± 0.5 kg and 16.3 ± 0.7 kg, respectively (49). Olsen and Strawderman showed that women who reported a decrease in their physical activity level during pregnancy had significantly greater gestational weight gain (33.1 lbs.) compared with women who either maintained or increased their physical activity level (27.6 lbs.), and only 38% of women gained within the Institute of Medicine recommendation for gestational weight gain (50). Gray-Donald et al. conducted an intervention study of pregnant women (n=219) who were assigned to an intervention group with diet counseling and exercise sessions or a control group (51). No significant treatment group differences were found for weight gain, diet, plasma glucose concentrations, birth weights, or maternal weight at six-weeks postpartum (51).

Other Concerns

Research indicates that women who exercise during pregnancy experience fewer side effects of pregnancy such as insomnia, anxiety, and somatic complaints than women who do not exercise (49). Sternfeld et al. found that women (n=388) who exercised at least 3 times per week for at least 20 minutes during pregnancy had lower symptom scores (e.g., heartburn, nausea, round ligament pain, insomnia, and leg cramps) during the first and third trimesters than those exercising less than 3 times per week or exercising less than once per week (5). Horns et al. found that women who engaged in physical activity (defined as 3 or more times per week) during the last trimester of pregnancy reported fewer of the common discomforts associated with pregnancy (e.g., swelling, leg cramps, fatigue, shortness of breath) than sedentary women (22).

Few studies have examined the psychological effects of physical activity in pregnant women, in spite of the fact that there is a higher rate of mood disturbances during pregnancy (52). Studies indicate improved mood overall during pregnancy and fewer symptoms of depression in the first postnatal week for women who participate in regular physical activity, defined as at least moderate intensity activity 3-5 times per week for a minimum of 20 minutes per session, during pregnancy (34). Marquez-Sterling et al. found that women who began an exercise program during their pregnancy had substantial improvements in aerobic fitness (measured by heart rate and duration of activity). Women also reported improved feelings of health and increased energy level relative to pregnant women not beginning an exercise program (53). Hall and Kaufmann evaluated the effects of a physical conditioning program on pregnancy outcomes and subjective pregnancy experience in 845 subjects (54). Pregnancy outcomes including length of labor, mode of delivery, length of hospitalization and gestational age, birth weight and Apgar score of newborn infants were more favorable in the exercise group (54). Additionally all participants reported positive subjective responses to the exercise program including level of tension, general comfort and self-image (54).

In another study, Garshasbi et al. investigated the effect of physical activity on low back pain by randomly assigning pregnant women (N=212) to a supervised exercise program three times per week or to a control group (55). The exercise group reported reduced back pain intensity and greater flexibility of the spine relative to the control group (55). Water gymnastics show potential for reducing back pain and reduced need for sick leave in pregnant women (56). Kihlstrand et al. randomly assigned 17 pregnant women to a weekly water gymnastics group or control and found that water gymnastics during the second half of pregnancy significantly reduced the intensity of back/low back pain in addition to a reduced number of sick-leave days because of back/low back pain relative to the control group (56).

Maternal Beliefs about Physical Activity During Pregnancy

Many reports indicate pregnant women's belief in the role of an adequate diet in the development of the fetus is appropriate, whereas their knowledge concerning the beneficial effect of physical activity is insufficient (1, 35). The majority of pregnant women decrease their physical activity in pregnancy to a considerable degree, and they do so out of concern about possible side effects for the course of pregnancy and delivery (40, 57).

Data from the literature show that attention is paid to injuries acquired as a result of physical exercises performed in pregnancy. Excessive flexibility and mobility of the joints caused by hormonal changes in pregnancy have led health care practitioners to excessively warn pregnant women about the negative effects of physical activity (1). Wojtyla et al. surveyed 2,852 women regarding their physical activity patterns before, during and after pregnancy and found that pregnant women in Poland are insufficiently physically active during pregnancy and most activity is limited to completing household chores (35). Additionally the study found that physicians taking care of women during pregnancy rarely discuss physical activity, and most often warn women against the negative effect of physical activity during this period, recommending the reduction of activity (35).

In a community-based participatory project, Promoting Healthy Lifestyles among Women, qualitative analyses of in-depth interviews with 10 pregnant and postpartum Latinas, and 10 people who influenced them were conducted (58). Thornton et al. found that absence of mothers, other female relatives, and friends to provide childcare, companionship for exercise and beliefs about the need to remain healthy and advice about food were prominent barriers that limited women's ability to maintain healthy practices during and after pregnancy (58). Additionally women received variable information from their physicians, husbands and friends regarding appropriate levels and types of physical activity creating confusion for these women (58).

Physical Activity and Body Image Satisfaction During Pregnancy

It has been hypothesized that during pregnancy, because of the body changes that occur, women's evaluation of their bodies are activated and emphasized (59). Given the current western ideals about body shape, which suggests that thin women are more beautiful, during pregnancy women may find themselves falling further from the cultural ideal of beauty (59). Goodwin et al. compared the body image satisfaction ratings of 25 exercising and 18 non-exercise pregnant women at various time points during pregnancy (60). For both the exercise and non-exercise groups, pre-pregnancy body image satisfaction ratings were more positive than early pregnancy ratings, and there were no differences found between the exercise and non-exercise groups' overall scores at pre-pregnancy, 17 weeks or 30 weeks gestation (60). However, the exercise group had more positive ratings compared to the non-exercise group on the combined waist, hip, bust and abdomen subscales of the Body Cathexis Scale at 30 weeks gestation (60). Marquez-Sterling et al. found that nine pregnant women who participated in an exercise program reported more improvements in body image than six non-exercising controls, and that these benefits of exercise extended to the later stages of pregnancy (53).

A study of 71 pregnant women compared body satisfaction of those who were high exercising (at least 90 minutes per week of moderate intensity activity) and low exercising (no or minimal amounts of activity) (61). Boscaglia et al. found that high exercising women were significantly more satisfied with their bodies at 15-22 weeks gestation compared to low exercising pregnant women, and tended to be more satisfied with their bodies at 23-30 weeks gestation (61). This study also found that both groups were less satisfied at 6 weeks postpartum compared to 6 months pre-pregnancy (61).

Gestational Weight Gain Recommendations

The World Health Organization (WHO) and other health authorities, have acknowledged the need to promote healthy behaviors during pregnancy, including healthy weight gain. Appropriate weight gain and adequate physical activity are now recognized internationally as critical health initiatives. An epidemiological study published in 2003 reported that regardless of pre-pregnancy BMI category, only about 50% of US women gained weight within the IOM recommended range. Historically behaviors like smoking and alcohol consumption during pregnancy were strongly discouraged and advocated against during pregnancy. Today, while these behaviors are still discouraged, health officials are shining the spotlight on healthy weight gain through dietary and physical activity interventions in pregnant mothers (62).

In 2009 the Institute of Medicine (IOM) released new, updated guidelines for gestational weight gain that can be applied to the general pregnant population (see Table 1). The guidelines are based on maternal pre-pregnancy BMI measurements. The

Table 1: 2009 Institute of Medicine Guidelines for Weight Gain during Pregnancy Based on Pre-Pregnancy BMI (21)

Pre-pregnancy BMI (kg/m^2)	Total Weight Gain
<18.5	12.5-18 kg (28-40 lb.)
18.5-24.9	11.5-16 kg (25-35 lb.)
25.0-29.9	7-11.5 kg (15-25 lb.)
≥30	5-9 kg (11-20 lb.)

ranges of healthy weight gain extend from as high as 40 pounds for an underweight mother to as little as 11 pounds for an obese woman. The weight gain recommendation for women in the normal weight BMI category is about 25-35 pounds, with most of the weight gain occurring in the third trimester (63).

Excessive Gestational Weight Gain and Mode of Delivery

Overall, studies support the link between exercise and more favorable labor and delivery outcomes, although findings are somewhat inconsistent. Regarding duration of labor, most studies have found no association between physical activity and shorter labor (17, 22, 49, 54, 64). Some studies indicate that exercise during pregnancy is associated with a lower risk of cesarean section (54, 65), whereas others have found no relationship (5, 17, 22, 32, 65).

A cesarean section (C-section) is stressful for the mother and is associated with longer postpartum recovery time and lower rates of breastfeeding, in addition to the typical medical risks associated with surgery (31). One study reported that for every 5 kg (11 lb.) of weight gain above the IOM recommendation, the risk for C-section delivery in women with induced labor increases by 13% (66).

In a large retrospective study of 8,293 women, 2,061 infants (25%) were delivered by C-section, of which 80% of the C-section deliveries were performed on women who exceeded the 2009 IOM recommendations for weight gain during pregnancy; whereas only 13% were performed on women who gained weight within the recommended ranges (20). A similar retrospective cohort study of 2,495 women reported that women with a normal pre-pregnancy BMI who gained excessive weight during pregnancy were 50% more likely to deliver by C-section than those who gained an appropriate amount of weight. This relationship may be due to the increased size of the baby. When a larger neonate is delivered there is increased risk for cehalopelvic disproportion, meaning that the child's head is too large to fit through the mother's pelvis (66). An infant who weighs more than 4 kilograms is identified as large for gestational age (LGA). Other explanations for increased rates of C-section delivery are slow cervical dilation, maternal hypertensive disorders, and unsafe fetal heart rate, all potentially a result of increased maternal gestational weight gain (66, 67).

Physical Activity and Return to Pre-Pregnancy Weight

Increased postpartum weight retention is associated with exceeding recommendations for weight gain during pregnancy (68). In a 2003 study, Butte et al. demonstrated that maternal fat retention at 27 weeks postpartum (5.3 kg) had significantly higher is women who gained above the IOM recommendation for gestational weight gain compared with those who gained within (2.3 kg) or below (-0.5

kg) recommendation (69). A similar study in 2009 tracked 1,656 women classified as obese throughout their pregnancies and found that obese women who gained more than 35 pounds during pregnancy were eight times more likely to retain more than 10 pounds one year postpartum (70). Body weight and body composition are important determinants of a mother's long-term health (68).

Rooney et al. observed 795 women though pregnancy and 6 months postpartum to examine factors that affect weight loss, then recorded weight 10 years later though a medical record review (71). The average weight gain from pre-pregnancy to 10-year follow-up was 13.9 pounds (6.3 kg) and there was no difference in weight gain by pre-pregnancy BMI (71). Women who gained less than the IOM recommendation for weight gain during pregnancy were 9 pounds (4.1 kg) heavier at follow-up, those who gained within the recommendations were 14.3 pounds (6.5 kg) heavier, and those gaining more than the recommendations were 18.5 pounds (8.4 kg) heavier (71). Additionally women who lost all pregnancy weight by 6 months postpartum were 5.3 pounds (2.4 kg) heavier at follow-up than women with retained weight, who weighed 18.3 pounds (8.3 kg) more at follow-up (71). This shows that excess weight gain and failure to lose weight after pregnancy are important and identifiable predictors of long-term obesity.

In a 15-year follow-up investigation Rooney et al. found that 30% of women were obese (BMI ≥ 30 kg/m^2), 27% were overweight (BMI ≥ 25 kg/m^2), 39% were normal weight (BMI 18-25 kg/m^2), and 4% were underweight (BMI<18 kg/m^2) (72). Weight gain over 15 years averaged 1.4 pounds (0.6 kg) per year and 21 pounds (9.5 kg) overall (72). Women who were obese at baseline gained the most amount of weight in the 15-year follow-up period and were the least likely to exercise aerobically (72). The results also showed that at 15-years postpartum 13% of women had developed diabetes or pre-diabetes, and 30% had developed coronary heart disease (72).

A groups of 401 pregnant women participated in a telephone-based behavioral intervention targeting gestational weight gain, healthy eating, exercise, and postpartum weight loss. This type of low-intensity behavioral intervention in pregnancy was found to reduce twelve-month postpartum weight retention and improve dietary restraint and self-weighing in those who completed the study (73). The intervention tended to increase the percentage of women who reached pre-pregnancy weight- 35.4% compared with 28.1% in the control group (73).

Maternal Physical Activity and Infant Birth Weight

Obesity in pregnancy is associated with fetal macrosomia, higher neonatal fat mass and an increased risk of obesity and poor metabolic health in childhood which persists into adulthood (74). Birth weight is strongly and consistently associated with both short-term and long term morbidity and mortality (75).

The UK Pregnancy Better Eating and Activity Trial (UPBEAT) (n=183) is a trial of a complex intervention designed to improve pregnancy outcomes through dietary changes and physical activity (74). Hayes et al. found light-intensity physical activity was lower in early pregnancy in women who delivered macrosomic infants and maternal sedentary time at 35-36 weeks gestation was positively associated and moderate-intensity physical activity was inversely associated with neonatal abdominal circumference (74).

Perkins et al. assessed the aerobic physical activity of 51 healthy pregnant women using accelerometers, heart rate monitoring and physical activity recall in relation to fetal growth rate (75). Aerobic physical activity was strongly and inversely associated with fetal growth and infants born to women in the highest quartile of physical activity weighed 1.34 pounds (0.61 kg) less than infants born to women in the lowest quartile (75).

Maternal Physical Activity and Effects on Childhood Weight Later in Life

The offspring of obese women are more likely to be obese than the offspring of lean women when they become pregnant themselves, perpetuating a cycle of obesity and its associated negative metabolic consequences (74). In addition, the IOM reports that there are inconsistencies in the literature regarding the association between gestational weight gain and child adiposity (21). Gestational weight gain is hypothesized to act on child adiposity directly through intrauterine programming and indirectly through birth weight (76, 77).

A longitudinal study of 3,600 children born in 2001 in the US showed that regardless of the maternal pre-pregnancy weight status, excess gestational weight gain (exceeding 2009 IOM recommendations according to BMI) was associated with an increase in offspring BMI at age five (76). A comparable study surveyed 11,994 adolescents enrolled in the Growing Up Today Study cohort and their mothers, members of the Nurses' Health Study II. The results showed that children born to women with excessive maternal weight gain during pregnancy (according to the 1990 IOM recommendations) had a significantly higher BMI and were 1.4 times more likely to be obese (78). A study of 4,234 subjects enrolled in the Copenhagen perinatal cohort (born between 1959-1961) correlated offspring BMI at 42 years of age to maternal gestational weight gain. The results of the analysis demonstrated a positive correlation between gestational weight gain and offspring BMI as adults (79).

Cnattingius et al. studied a cohort of 162,676 mothers and their first-born offspring to examine the association between mothers' birth weight indexed to gestational age and adult BMI and these factors' combined effect on risk of having a large-for-gestational-age (LGA) offspring (80). Compared with mothers born at an appropriate birth weight for gestational age, mothers born LGA had increased risk of adult overweight or obesity (80). In addition the risk of having a LGA offspring was highest among women with a high BMI >30 kg/m^2 who also had a high birth weight for gestational age (80). These results show that prenatal conditions are an important contribution to the obesity epidemic and preventing LGA births may help to slow the intergenerational cycle of obesity (80).

Hypothesized Cycle of Inactivity and Weight Gain

In non-pregnant women there is a close relationship between physical activity levels and health status, but this has not been well documented in the pregnant population. Figure 1 represents a hypothesized cycle of inactivity and weight gain for women before, during, and after pregnancy and the impact weight gain has on fetal and childhood outcomes.

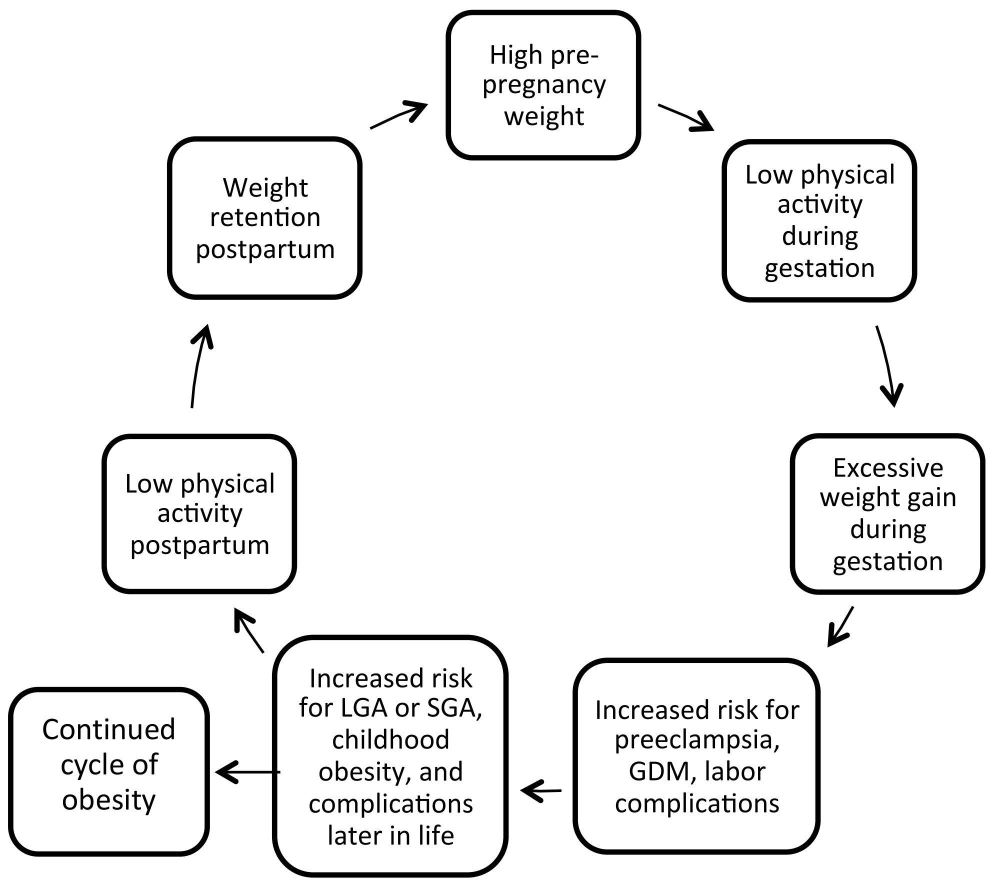

Figure 1. Hypothesized cycle of inactivity and weight gain in women before, during, and after pregnancy and the impact on fetal and childhood outcomes

Use of Accelerometers to Measure Physical Activity During Pregnancy

Physical activity is a behavior that involves bodily movements resulting in energy expenditure. When assessing physical activity, a common goal is to identify the frequency, duration, intensity, and types of behaviors performed during a period of time. Direct measures of physical activity include motion sensors such as accelerometers, pedometers, heart-rate monitors, and multiple-sensor devices.

Previous epidemiological research suggests that most women (~50-60%) do not participate in regular physical activity during pregnancy (29). However, these estimates are based on use of crude measures that are not validated and may be prone to error (81). Given the limited research using objective, comprehensive and validated methods, there is currently no commonly accepted measurement tool to assess physical activity during pregnancy (82).

The assessment of maternal physical activity during pregnancy is important due to the close relationship between physical activity levels and health status, and to understand the relationship, it is important to accurately estimate the physical activity levels in the pregnant population (83). Due to the variety of physical activity patterns found during pregnancy, valid tools should be used to avoid measurement error. Self-report physical activity surveys may not provide an accurate estimate of physical activity (82). Pregnant women who are obese may spend more time at lower intensity activities but may perceive the activities to be moderate or vigorous activities (81, 82). In general, accelerometers are recognized as a valid tool to assess physical activity. Unfortunately, the use of accelerometers has not been readily documented or validated in pregnant women (83).

Accelerometers are small wearable monitors that record accelerations in gravitational units on one or more planes at sampling rates >1 time/second (typically 40-100 Hz) (84). Captured accelerations are then processed to a lower resolution (i.e., an epoch) and then calibrated against a known criterion measure (e.g., oxygen consumption, doubly-labeled water). Most of the existing calibration studies rely on a unit-less intensity metric or “counts” and then apply thresholds to summarize data to estimate the duration and frequency of physical activity in sedentary, light, moderate, and vigorous intensities (84). There is controversy over the appropriate pre- and post-processing methods and thresholds for various populations and desired physical activity component (84).

Most accelerometer measurement systems perform poorly compared to the gold standard of doubly labeled water technique, and calibration studies have shown a wide range of correlations (r=0.45 to 0.93) with measures of oxygen consumption and METs (82, 84, 85). This wide range is due to a number of protocol-related variations including the monitor under study (some monitors and their associated algorithms are more accurate than others), monitor placement (hip, wrist, ankle, trunk), activities under investigation (e.g., ambulatory physical activities are more accurate than non-ambulatory physical activities such as cycling and household chores), and context (laboratory-based studies have greater accuracy than free-living studies (84).

Given the complexity, cost, expertise required to use and the limited availability of the doubly labeled water technique, the accelerometer is more feasible in community-based research settings. The appeal of the accelerometer for measuring physical activity is the detailed and relatively precise manner, with minimal invasiveness, in which frequency, duration, patterns, and intensity of activity can be monitored over days, weeks, and even longer (84). In addition to measuring step counts, the accelerometer measures duration, frequency and intensity of activity, thereby providing specific information on physical activity in free-living conditions (85). Many accelerometers have been tested under laboratory conditions during standardized activities, in field settings against portable calorimeters and in the controlled environment of a whole room calorimeter (86-88).

The Actigraph GT3X (Actigraph, Pensacola, FL., USA) is a lightweight (27g), compact (3.8 x 3.7 x 1.8 cm) instrument that is powered by a rechargeable lithium polymer battery (89). It uses a solid-state tri-axial accelerometer to collect motion data on 3 axes; vertical (Y), horizontal right-left (X) and horizontal front-back axis (Z). The Actigraph also records vector magnitude (VM) data. The accelerometer output is digitalized by a 12-bit analog-to-digital converter at a rate of 30 Hz per second. Each sample is summarized in an "epoch" and the output of the Actigraph is reported in "counts". The counts obtained in a given time period are linearly related to the intensity of the subject's physical activity during this time.

Accelerometers function by integrating a filtered digitized acceleration signal over a investigator-specified time interval (1 sec, 4 sec, 15 sec, or 60 sec or longer), commonly referred as an epoch (90). At the end of each epoch, the sum index of physical activity is calculated; this process is repeated until data collection is completed (90).

Data is often collected in 10-second epoch intervals to obtain the most precise data. After data import, all files are converted to standard 60-second epoch intervals, which is generally accepted for an adult population. 60-second epoch intervals are consistent with the calibration studies performed from which cut-points were derived to determine the amount of time spent in sedentary, light, moderate, MVPA or vigorous physical activity (91-97).

Accelerometer Data Processing Procedure

The first step in calculating physical activity from the accelerometer is to perform a wear-time validation analysis that allows invalid data (or data collected when the device was not worn) to be identified and excluded from further analysis. The Troiano technique was developed to determine periods of time when the accelerometer was not worn when data was collected as part of the 2003-2004 National Health and Nutritional Examination Survey (NHANES) dataset (91). Non-wear-time was defined as a period of 60 minutes or more of zero cpm no more than 2 minutes of counts between 0 and 100 (91). When non-wear-time is identified, the counts for those minutes are set to “missing”. Spurious data, defined as cpm ≥30,000 or ≥10 minutes of the same repeated non-zero counts are also set to “missing” (91).

Accelerometer Cut-Point Measures used to Determine Intensity of Physical Activity

Cut-points are used to assign physical activity data measured in cpm into intensity categories. Each 60-second epoch is categorized into an intensity category based on specific cpm cut-points (see Table 2) (98). Depending on the cut-point reference used, activity may be categorized as sedentary, light, moderate or vigorous. The term moderate to vigorous physical activity (MVPA) is often used to refer to the amount of time a participant spends at or above a "moderate" cut-point level, thus indicating "significant" activity. The ActiLife output include the amount of time (of total accelerometer valid wear-time) spent performing MVPA, the percentage of time spent performing MVPA, and the average amount of time spent performing MVPA per day over the period of data collection (98). Two commonly used cpm cut-point ranges established to classify sedentary, light, moderate, and vigorous physical activity were developed by Swartz, et al., 2000 and Troiano, et al., 2008, and are summarized in Table 2 (91, 92).

Table 2. Physical Activity Intensity Categories

Activity Level	**Swartz et al. (92) (cpm)**	**Troiano et al. (91) (cpm)**
Sedentary	N/A	0-99
Light	0-574	100-2019
Moderate	575-4946	2020-5998
Vigorous	≥4947	≥5999

The cut-points established by Swartz et al. were derived from data from seventy participants while they completed one to six activities including yard work, housework, family care, occupational tasks, recreation activities, and conditioning activities. Five to 12 participants completed each activity. Each participant wore two uniaxial accelerometers simultaneously, one was worn on the wrist and the other was worn on the hip.

The cut-points established by Troiano, et al. were derived using data from the 2003-2004 NHANES, a cross-sectional study of the civilian, non-institutionalized, U.S. population. Participants were asked to wear a uniaxial accelerometer 24 hours a day for 7 consecutive days. More than 6,300 participants provided at least 1 day of valid accelerometer data and more than 4,800 participants provided four or more days of valid accelerometer data (91).

The Troiano and Swartz cut-points were used by Evenson et al. to characterize physical activity in pregnant women (n=359) (27). Each woman wore an accelerometer for 24 hours a day for seven consecutive days during each trimester. The monitor recorded 60-second epochs and the Troiano technique was used to define wear-time as previously described. "Non-wear-time" data was coded as "missing" as were cpm of ≥ 30,000 or at least 10 minutes of the same repeated non-zero counts. A valid "measurement day" was defined as the length of time in which at least 50% of the sample wore the accelerometer. This value was multiplied by 70% to define a compliant day. Participants had to provide four or more days of compliant data to be included in analysis.

A summary of the Evenson et al. results is presented in Table 3. The average accelerometer wear-time was 12.3 hours/day, with an average of 273 counts per minute (27). Using the Troiano cut-points, pregnant women engaged in an average of 12.0 minutes/day of moderate physical activity and an average of 0.3 minutes/day of vigorous physical activity, or an average of 12.3 minutes of MVPA/day (27). It is important to note that when using the Troiano method, 67% of the days had no recorded minutes of vigorous physical activity.

When the Swartz cut-points were applied to the data, pregnant women engaged in an average of 111.3 minutes/day of moderate physical activity, 0.6 minutes/day of vigorous physical activity, and a total an average of 111.8 minutes of MVPA per day (27). Most pregnant women in this study spent more than half of the monitored day performing sedentary activity and did not meet recommendations for physical activity

Table 3. Counts per minute and Minutes of MVPA of Women During Pregnancy (27)

	1st Trimester	**2nd Trimester**	**3rd Trimester**	**Overall (mean)**
Counts per minute (cpm)	263.2 ± 17.14*	284.8 ± 13.75	249.3 ± 11.57	272.7 ± 6.28
Troiano Cut-Points (minutes/day)	11.5 ± 1.97	14.5 ± 1.56	7.6 ± 0.59	12.3 ± 0.88
Swartz Cut-Points (minutes/day)	106.3 ± 7.54	116.6 ± 4.55	105.7 ± 7.11	111.8 ± 3.03

***** Mean ± standard error

(27). Time spent in MVPA was significantly higher in the first and the second trimester compared to the third trimester (27). This finding is consistent with longitudinal studies of pregnant women, where physical activity declined from second to third trimesters based on either self-reported physical activity or accelerometer data (99, 100). As illustrated in Table 3, accelerometer data analyzed using the Swartz et al. cut-points likely provide a higher number of minutes in MVPA and as a result are more likely suggest that women will meet the physical activity recommendations during pregnancy than the Troiano et al. cut-points.

Metabolic Equivalents of Task

Metabolic Equivalents of Task (MET) is an estimate of the energy cost required to perform physical activities and is defined as the rate of energy consumption associated with preforming a specific activity, with respect to the rate of energy consumed, during a reference treadmill activity. Algorithms have been developed to determine the average hourly, daily, and per-epoch metabolic rate associated with various activities. One MET is defined as the amount of energy expended at rest; which is equivalent to the Basal Metabolic Rate (BMR). Formulas have been devised to link MET rates to cpm.

Freedson et al. (1998) developed a MET algorithm from accelerometer data obtained from 50 adults (mean age 24.8 ± 4.2 years) while they walked or ran on a treadmill at three different speeds (4.8, 6.4, and 9.7 km/hr [3.0, 4.0, and 6.0 mile/hr]) while simultaneously measuring oxygen consumption by indirect calorimetry (95). Results indicated a strong relationship between cpm measured with an accelerometer and oxygen consumption (r=0.88) measured by indirect calorimetry (95). The Freedson et al. algorithm is: MET rate = 1.439008 + (0.000795 * CPM).

METs are used as a means to express intensity and energy expenditure of activities in a way that is comparable among people of different weights. Additionally this number is used to provide a general idea of physical activity and energy expenditure above basal metabolic rate. MET measures can be compared against the Compendium of Physical Activities to generate examples activities that fall within a specific MET range (86, 87).

Physical Activity Using Accelerometers During Pregnancy and the Postpartum Period

In a study by Bell et al. physical activity was measured in overweight and obese women using an accelerometer at a median of 12 weeks gestation (101). Study participants were asked to wear the accelerometer for seven consecutive days for "as much of the day as feasible", removing it for bathing, swimming and sleeping at night and to complete a daily log indicating when and why the monitor was not worn. Data files were included in the analysis if the device was worn for at least 3 days (101). The authors found that after imposing cut-points established by Freedson, et al. women spent a median of 35 minutes performing MVPA (95, 101).

In a different study, physical activity was measured by accelerometers in 132 overweight or obese women at 24 weeks postpartum and 10 months later (102). Women wore the accelerometer for 12-14 hours for a median of 7 days at both time periods. Using cpm cut-points established by Colley et al. (103), women accumulated a median of 6.9 minutes/day of MVPA at the baseline measure and 8.8 minutes during the follow-up measure. The authors found that while there was a small increase in physical activity as time progressed in the postpartum period women fell short of meeting the recommendation of 150 minutes/week (102).

In a 2012 study by Evenson et al., 181 women wore an accelerometer at 3-months and 12-months postpartum (104). Average wear-time was between 12-13 hours at both time points. The data was analyzed using Swartz et al., Troiano, et al., and Freedson, et al. cut-points (91, 92, 95). Findings were consistent using Freedson and Troiano cut-points; women averaged 17-21 minutes/day of moderate activity (91, 95). However, using Swartz cut-points women accumulated 276-287 minutes/day of moderate activity (95). Regardless of the cut-points used, women only had 1-3 minutes/day of vigorous intensity activity, which accounted for less than 1% of total activity. Evenson et al. also reported cpm, which represent raw data without imposition of cut-points. The cpm at the three-month postpartum measure was 364, while at 12-months the cpm measure was 394 (104). This type of analysis shows a slight increase in moderate intensity physical activity from 3-months to 12-months postpartum but regardless, women did not meet the established physical activity recommendation at either time point.

In the UPBEAT pilot study Hayes et al. observed physical activity in 183 overweight or obese women at three time points during pregnancy (16-18 weeks, 27-28 weeks, and 35-26 weeks gestation) (105). Women wore an accelerometer for three or more days for a minimum of 500 minutes/day. Using the Freedson et al. cut-points, during the 15-16 weeks measure women spent 39.0 minutes (4.8%) of wear-time performing MVPA, during the second trimester women spent 34.5 minutes (4.3%) of wear-time performing MVPA, and during the third trimester women spent 23.3 minutes (3.0%) of wear-time in MVPA (95). The authors concluded that physical activity in early pregnancy was the factor most strongly associated with physical activity in later pregnancy and that women should be encouraged to participate in physical activity before becoming pregnant to maintain their activity levels during pregnancy (105).

Using NHANES cross sectional data, Hawkins et al. determined the physical activity intensity levels of pregnant women using a population-based sample of 294 women (106). Women wore the accelerometer for 4 or more days with 10 or more hours of wear-time per day. Using the Freedson et al. cut-points women accumulated a median of 71 MVPA minutes/day, 78 MVPA minutes/day, and 69 MVPA minutes/day in the first, second, and third trimesters, respectively (95, 106).

In a secondary analysis of data obtained during a randomized controlled trial, Ruifrok et al. analyzed accelerometer measurements from 111 women around 15 weeks and 32-35 weeks gestation (107). Women were included if they accumulated at least 8 hours of accelerometer wear-time. Using Troiano et al. cut-points women performed 24 MVPA minutes/day at 15 weeks gestation and 18 MVPA minutes/day between 32-35 weeks gestation (91). Additionally 53% of women in this study gained more weight than advised by the IOM (21). The amount of gestational weight gain was even more pronounced in women who were overweight or obese, with 68.9% and 59.8% respectively (106). Hawkins et al. found no significant associations between time spent in MVPA or sedentary behavior and gestational weight gain or infant birth-weight (106).

In one of the few longitudinal studies in pregnant women using accelerometers, Van Poppel et al. assessed physical activity at 15, 24, and 32 weeks gestation in 24 overweight or obese women (108). Women were included in the analysis if they wore the accelerometer for 4 consecutive days with at least 8 hours/day of wear-time. Using Freedson et al. cut-points women accumulated an average of 212, 183, and 159 minutes/week of MVPA in the first, second and third trimesters respectively (108). This showed that, on average, women met the CDC recommendation of 150 minutes of MVPA per week (26). Van Poppel et al. also concluded that in overweight or obese pregnant women, MVPA was associated with improved insulin sensitivity, insulin response, and decreased triglycerides at 32 weeks of pregnancy (108). These findings also reiterate the importance of counseling pregnant women who are at risk of developing GDM on the importance and benefits of physical activity throughout pregnancy.

Summary and Limitations

Research indicates that exercise during pregnancy likely has a positive effect on maternal and infant outcomes. Observational studies suggest that exercise during pregnancy is related to various health benefits, including reduced rates of preeclampsia, hypertensive disorders of pregnancy, gestational diabetes, cesarean sections, low back pain, anxiety, nausea, heart burn, insomnia, and leg cramps (109). In addition, some observational studies have linked exercise during pregnancy to a reduced risk of excess gestational weight gain, although findings across studies are somewhat conflicting.

Many of the studies that assessed physical activity during pregnancy were observational; therefore there is potential for bias and confounding results. For example, pregnant women who are physically active may have different views on wellness and nutrition and/or have better overall health than women who are not physically active during pregnancy. These differences in perceived health benefits may alter the relationship between physical activity and pregnancy outcomes. Randomized control trials may overcome this limitation, however, one problem with this design is that participants may be asked to complete the exercise sessions in a laboratory setting, so that the results may not be generalizable to a free-living situation.

Another limitation of the current literature is that many studies relied exclusively on self-reported documentation of physical activity; objective measures of physical activity such as accelerometers were rarely used. Studies based on self-report of activity used a variety of measurement tools, which makes it difficult to compare results across studies. Another limitation is that some studies defined "exercise" as physical activity that occurred one or more times per week, which may be too low of a frequency to detect difference in outcomes between exercisers and non-exercisers. In summary, previous research studies are limited by observational designs and inadequate assessment measures, which do not control for confounding factors. To address these limitations, we proposed to analyze data from the OHSU Pregnancy, Exercise, & Nutrition (PEN) study to determine if physical activity impacts gestational weight gain and weight retention during the early postpartum period.

CHAPTER 3 METHODS

General Study Design

The principal goals of this exploratory sub-analysis were to examine the relationships between maternal physical activity and weight gain during pregnancy and maternal weight retention at 12 weeks postpartum. This sub-analysis used data collected from women who participated in the Oregon Health & Science University (OHSU) Pregnancy Exercise and Nutrition (PEN) Feasibility Study between 2011-2014. The PEN study was a prospective, randomized, controlled, feasibility study of a new, interactive curriculum designed to improve diets and physical activity levels of women throughout pregnancy. For the purposes of this analysis women were grouped together regardless of control or intervention group assignment.

Subjects

Participants were pregnant women who were Oregon Health & Science University (OHSU) employees or spouses of OHSU employees. Participants were recruited to participate in the PEN study in their first trimester of a single gestation pregnancy. Recruitment methods included displaying posters and flyers around the campus and hospital, pamphlets placed in obstetric clinics, and notices included on the OHSU internal website. Women judged to be healthy by self-report, review of medical history, medication use, lab screenings, and physical exam were considered eligible for participation. Inclusion and exclusion criteria are presented in Table 4. A physician's note was required for each participant enrolled in the PEN Study specifying that their patient may be enrolled in the program, and they would share relevant patient data.

Table 4. Inclusion and Exclusion Criteria for Participants in the OHSU PEN Study

Inclusion	Exclusion
• Healthy pregnant adult	• Type 1 or Type 2 Diabetes Mellitus
• OHSU employee	• Cardiovascular disease
• Spouse of an OHSU employee	• Obstructive lung disease
• Single gestation pregnancy	• Musculoskeletal dysfunctions
• First trimester of pregnancy	• Hypertension or previous diagnosis of hypertension
	• Use of anti-hypertensive medications
	• Elevated fasting blood sugar (>110 mg/dL) at entry
	• Exceeding 40 years of age
	• Smoking and/or drinking during pregnancy

Each participant provided informed consent and signed Health Insurance and Accountability Act authorization forms before enrollment. All study-related procedures were reviewed and approved by the OHSU Institutional Review Board.

Randomization

Participants were randomly assigned into the intervention group or control group. Group assignment was balanced for pre-pregnancy body mass index (BMI) and age. To accomplish this balanced randomization, information describing each group of 10 new participants was entered into a table that included participant identification number, BMI, and age. The table was ordered by BMI, and participants with the same or similar BMIs were sorted by age. Participants with similar BMI and age were paired and assigned to the control or intervention group using the iPhone application "Coin Flip +". Two steps were taken to determine group assignment. The first step ordered the participant pair. Heads indicated the participant be listed in the first pair, and tails indicated the participant be listed in the second. The second step assigned the first participant of the pair to one of the two groups. Heads indicated the participant was assigned to the intervention group, and tails indicated the participant was assigned to the control group.

Control Arm

Women randomized to the control group received standard care by their health care providers during pregnancy. As control participants in the PEN study, they received a handout entitled Pregnancy: Staying healthy and safe created by the U.S. Department of Health and Human Services Office on Women's Health Pregnancy. This handout included diet and fitness recommendations during pregnancy, information on smoking cessation and substance abuse, and other pregnancy-related health information.

Intervention Arm

Women randomized to the intervention group participated in a scripted, team-based, peer-led interactive curriculum, and accompanying web-based intervention to promote healthy dietary and physical activity practices during pregnancy. The intervention group was expected to attend 20 weekly, 30-minute, peer-led educational sessions, and follow dietary and physical activity recommendations included in the educational curriculum.

Curriculum

The PEN curriculum was developed by the faculty and staff of the Division of Health Promotion & Sports Medicine at OHSU, based on methods shown to successfully improve health behaviors in other workplace wellness interventions. A key component of these interventions is a team-based learning and social support paradigm. The curriculum included nutrition and physical activity guidelines during pregnancy. Curriculum materials included a scripted team leader manual (the leader rotated among team members each session), a team member workbook, and a Health & Wellness Guide. Group sessions were held weekly for about 30 minutes, during a time that was agreed upon by members of the group. The 12-session OHSU employee general wellness program, entitled Healthy Team Healthy U (HTHU) provided the foundation for the 20 sessions. PEN curriculum added eight additional pregnancy specific sessions.

Physical Activity in the PEN Curriculum

The PEN study curriculum emphasized the importance of physical activity using goals, activities, challenges, and pregnancy-specific exercises. Participants were encouraged to accomplish 10 physical activity goals between sessions and throughout the program. A pedometer was given to each participant during their first session with a goal to achieve 10,000 steps a day for the duration of the program. A weekly goal of physical activity for 30 minutes a day at least 4 days a week was set. A number of activities, both aerobic and strength training exercises were encouraged throughout the curriculum. Benefits, precautions, and terminology surrounding physical activity and energy balance were all explored and explained within the curriculum. Participants were given a complimentary, five-month membership to a gym or fitness facility of their choice (up to $50 per month). Approximately 25% of the total curriculum was dedicated to physical activity.

Demographic Information

Each participant completed a questionnaire to provide the following demographic information: ethnicity, race, education level, employment status, household income, and number of people in the household. They also provided information about their personal pregnancy history including delivery date, gestational age of the infant in weeks at delivery, birth weight, gender, type of delivery, place of delivery, and preterm labor delivery status for each birth prior to their current pregnancy.

Measurements

Study measurements were obtained during first (baseline), second, and third trimester visits, and at the 12-week postpartum visit.

Trimester Visits

After baseline measurements were collected during the participant's first trimester, follow-up data were collected at approximately 22 and 32 weeks of gestation and at a postpartum visit approximately 10-14 weeks after delivery. Visits consisted of weight and blood pressure measurements, and collection of urine and blood samples. After each study visit participants were given an accelerometer to wear for seven days. They were not required to keep an activity log or to provide a record of daily on/off wear-time.

Weight and Height Measurements

Trained research staff measured participant weight and height in the OHSU Health Promotion & Sports Medicine Human Performance Lab. Participants wore light clothing and were without shoes. Weight was obtained with an electronic scale to the nearest 0.5-gram [Fairbanks; HS 110AX Class III; (Kansas City, MO)]. Height was measured with a stadiometer to the nearest 0.01-centimeter (Invicta Plastics Limited; Design Application No. 2007246; Leicester, England). Body mass index was calculated as the weight in kilograms divided by the height in meters squared.

BMI= [weight (kg)]/[height (m^2)]

Accelerometer

An Actigraph tri-axial accelerometer (Actigraph, Pensacola, FL., USA) was provided to each participant who was told that the accelerometer would be used to collect information about physical activity. Participants were told to wear the accelerometer on the right hip in a straight line above the right knee with the black button facing up, making direct contact with the body (89). Participants were asked to start wearing the accelerometer on the morning of their appointment, and to stop wearing the device seven days later. The accelerometer was to be worn continuously, other than when swimming for longer than 30 minutes, showering, and sleeping.

Physical Activity Data Platform

ActiLife 6 Data Analysis Software (Actigraph, Pensacola, FL., USA) an actigraphy data analysis and management platform, was used to prepare ActiGraph devices for data collection and to download, process, score and securely manage collected data

(98). The ActiLife software contains a wide selection of independently validated, industry standard algorithms that can be used to score data based on the study population. Software analytics included energy expenditure, MET rates, cut-points, activity bouts, sedentary analysis, inclinometer, sleep scoring, GPS correlation, data comparison, and batch data exports (98).

Data Acquisition and Cleaning

Data was imported from the ActiGraph using ActiLife software. Once acquired, the data was analyzed to identify days with valid accelerometer wear-time. A participant must have worn the device for 6 hours or more (≥ 360 minutes) a day to be considered valid or compliant. Next, an individual's data was screened to determine the number of compliant days within each 7-day collection period; data sets with four or more days of data, each with 6 or more hours of valid wear-time was considered compliant and included in analysis. Data meeting these criteria was used in several ways. First, using the Freedson et al. equation we calculated average daily METs (95). Second, using mean counts per minute (cpm) we evaluated the raw data, which represents average intensity of physical activity without imposing cut-point decisions (110). This is important for comparison purposes for accelerometer and other physical activity data. The cpm value was derived by dividing the sum of the total counts measured in a day or over a specific period by the total number of minutes that the accelerometer was worn on each compliant day. Third, moderate to vigorous physical activity (MVPA) was calculated in two ways, first using the cut-points established by Troiano et al. (91), then using cut-points derived by Swartz et al. (92). Fourth, using relative values, average percent time per day spent performing light and MVPA was determined. These measures were calculated from data obtained during the first, second, third trimesters of pregnancy, overall throughout pregnancy, and at three-months postpartum.

Output data was exported to an Excel spreadsheet and box-plots were used to identify outliers and skewedness. Data points that stood out from the others were investigated to ensure that the data was transferred and/or entered correctly. Data analysis was performed using STATA Data Analysis and Statistical Software program (Copyright 1996-2015 StataCorp LP, 4905 Lakeway Drive, College Station, TX 77845 USA).

Statistical Analysis

As illustrated in Figure 2 we described the patterns of daily physical activity in Metabolic Equivalents (METS), mean counts per minute (cpm) and amount of time spent in light, moderate, moderate to vigorous and vigorous physical activity, as measured by the accelerometer, of participants in the Pregnancy Exercise & Nutrition (PEN) feasibility study during the first, second, and third trimesters of pregnancy, at 3 months postpartum, and overall. Descriptive statistics were used to characterize study participants, and included means, ranges, and frequencies of participant demographic information. Descriptive statistics were also used to characterize patterns of physical activity, and included minutes spent in each intensity level of activity (light, moderate, moderate to vigorous [MVPA], and vigorous) for each trimester of pregnancy, three-months postpartum, and overall.

As illustrated in Figure 2, differences in mean amount of physical activity in minutes per day of moderate to vigorous physical activity (MVPA) performed during the first, second, and third trimesters of pregnancy, at 3 months postpartum, and overall were compared between women who were overweight/obese (BMI ≥ 25 kg/m^2) or normal weight (BMI <25 kg/m^2) based on self-reported pre-pregnancy weight. Two-sided, unpaired, t-tests were used to determine the significance of differences in MVPA between groups. P-values less than 0.05 were considered significant.

As illustrated in Figure 3, the relationship between maternal pre-pregnancy BMI and physical activity in minutes per day of MVPA during pregnancy was determined. As illustrated in Figures 4, 5, and 6 the relationship between amount of physical activity in minutes per day of MVPA, and maternal gestational weight gain (indexed to week of gestation age at delivery) and maternal weight retention at 3 months postpartum was determined.

We hypothesized that women who met the physical activity recommendation of 30 minutes of MVPA per day at least 4 days per week during the first, second, and third trimesters, and overall would be more likely to meet the IOM recommendations for weight gain during pregnancy (indexed to week of gestation age at delivery) than those who did not meet the physical activity recommendation. We used odds ratios with 95% confidence intervals to determine the impact of maternal physical activity on meeting or exceeding the IOM recommendation for weight gain.

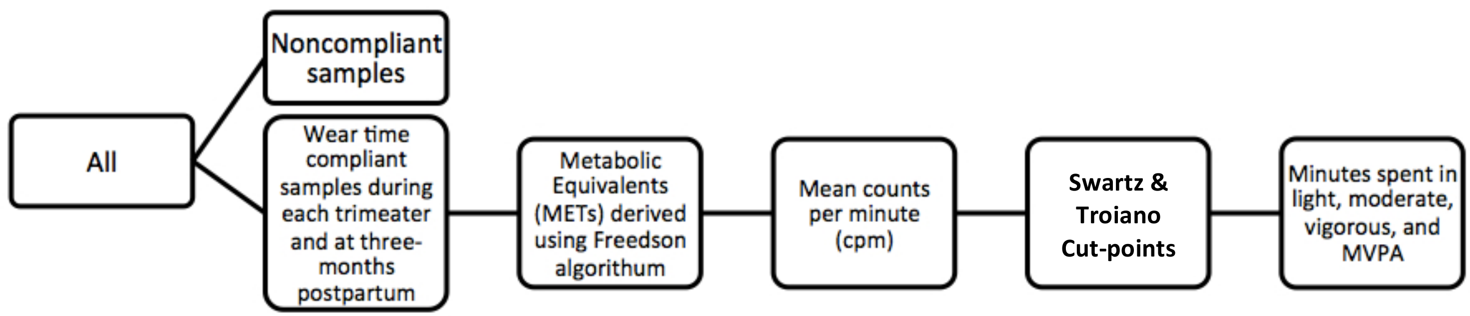

Figure 2. Analysis plan to describe physical activity patterns among all participants in the OHSU PEN feasibility study participants using Swartz and Troiano cut-points

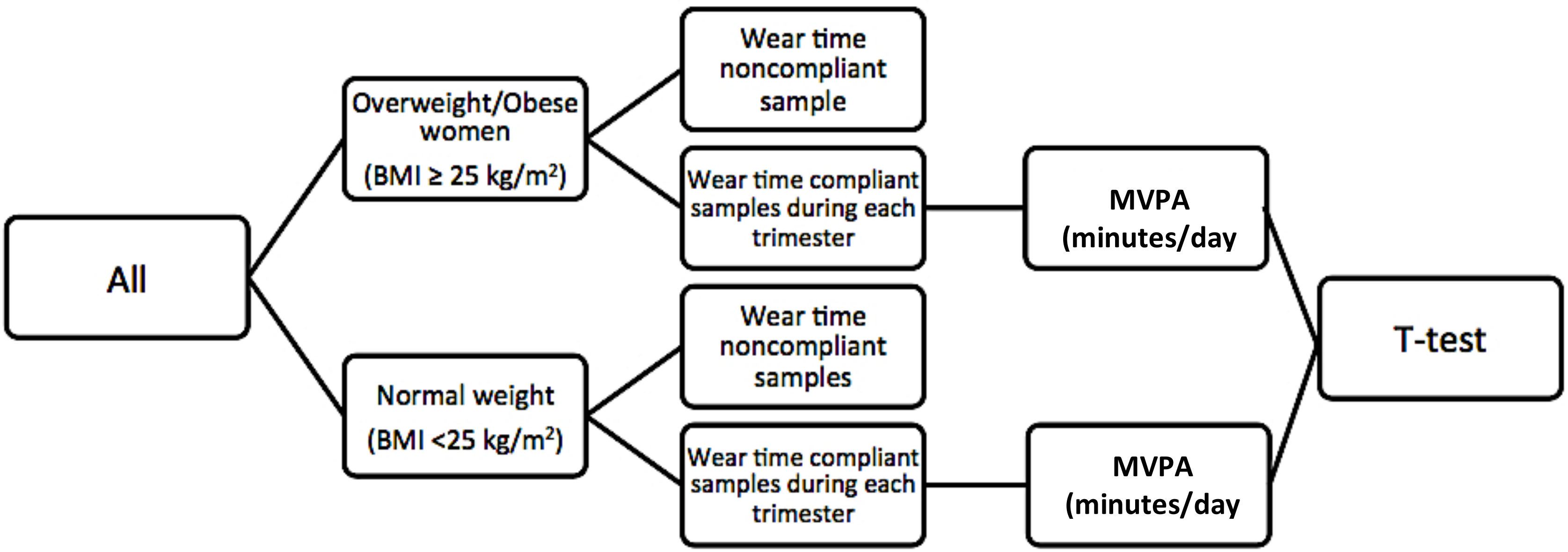

Figure 3. Analysis plan to compare differences in physical activity patterns among normal weight and overweight/ obese participants in the OHSU PEN feasibility study using Swartz and Troiano cut-points

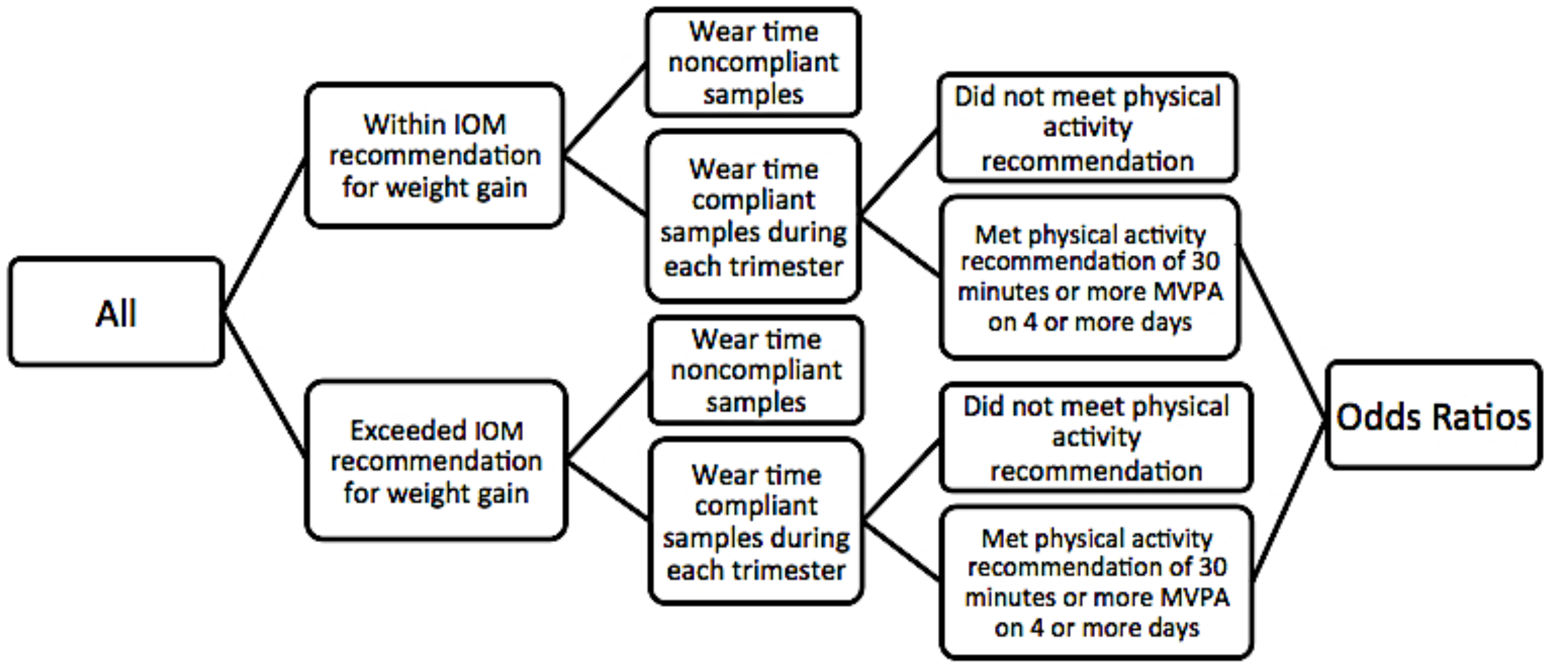

Figure 4. Analysis plan to evaluate the impact of maternal physical activity on meeting or exceeding the IOM recommendations for weight gain in all participants in the OHSU PEN feasibility study using Swartz and Troiano cut-points

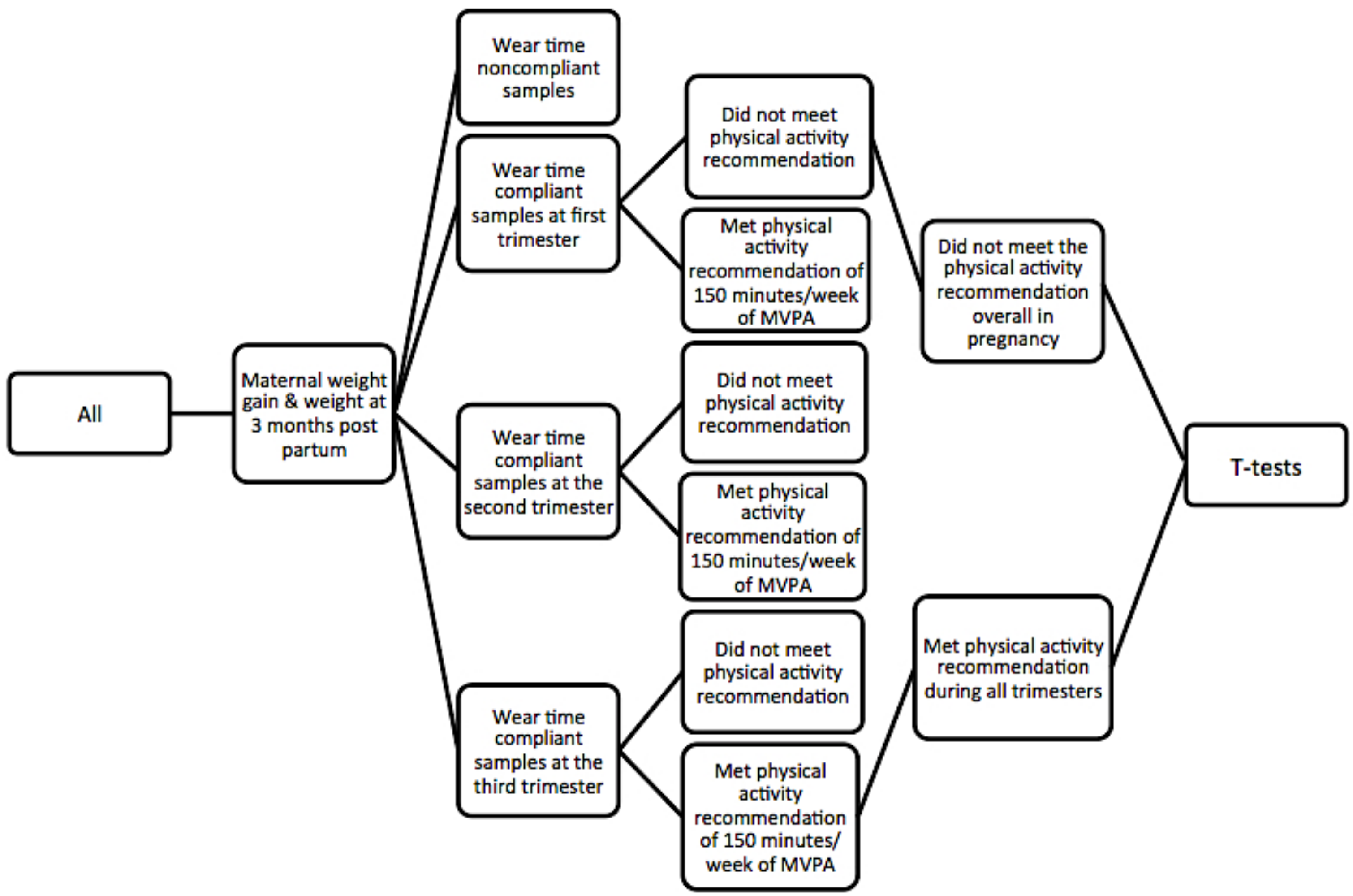

Figure 5. Analysis plan to compare maternal weight retention at three-months postpartum to physical activity throughout pregnancy among participants in the OHSU PEN feasibility study using Swartz and Troiano cut-points

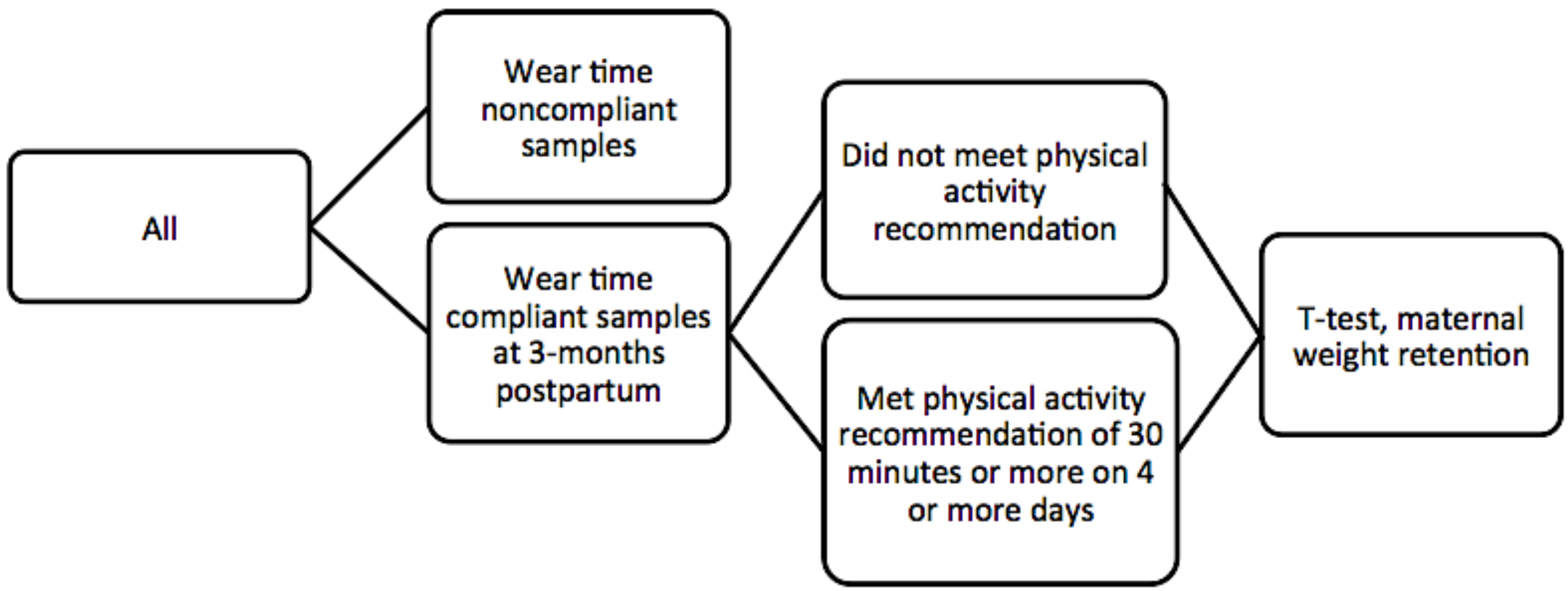

Figure 6. Analysis plan to compare maternal weight retention among those who met or did not meet the physical activity recommendation at three-months postpartum among participants in the OHSU PEN feasibility study using Swartz and Troiano cut-points

In addition, we hypothesized that at 3 months postpartum, mean maternal weight as a percent of self-reported pre-pregnancy weight, would be lower among women who met the physical activity recommendation of 30 minutes a day of MVPA at least 4 days a week at each trimester during pregnancy than those who did not meet the recommendation during any one or all trimesters of pregnancy. We used two-sided, unpaired, t-tests to determine the significance of differences in physical activity between groups at each time point and overall. P-values less than 0.05 were considered significant.

Finally we hypothesize that at 3 months postpartum, maternal weight as a percent of self-reported pre-pregnancy weight, would be lower among women who met the physical activity recommendation of 30 minutes a day at least 4 days a week at 3 months postpartum than those who did not meet the recommendation. We used a two-sided, unpaired, t-test to determine the significance of the difference in physical activity between groups. A p-value less than 0.05 was considered significant.

Calculations

Total gestational weight gain was defined as the difference between the last recorded weight before delivery (per Epic chart review or physician report) and self-reported pre-pregnancy weight. Maternal weight retention was calculated by subtracting self-reported pre-pregnancy weight from maternal weight at three-months postpartum.

Recommended weight gain was indexed to week of gestation at delivery using the specific IOM recommended weight gain ranges assigned to each week of delivery

(21). For example, a participant with a normal weight pre-pregnancy BMI who delivered at 40 weeks gestation would have a recommended weight gain range of 25-35 pounds. However, a woman in the same BMI category who delivered at 37 weeks of gestation would have a recommended weight gain range of 22-32 pounds (accounting for one pound per week weight gain in the third trimester).

Percent recommended weight gain was calculated as the percent of the highest value of the IOM recommended weight gain range [(percent recommended weight gain = actual weight gained/highest recommended weight gain) * 100]. For example, if a participant with a normal weight pre-pregnancy BMI had a recommended weight gain range of 25-35 pounds and gained 35 pounds, this would equate to 100% of recommended weight gain [(35/35)*100=100%].

Weight retention at three-months postpartum was calculated as the difference between weight at three-months postpartum and pre-pregnancy weight [weight retention = (weight at three-months postpartum / pre-pregnancy weight) *100]. For example, a women who had a pre-pregnancy weight of 140 lbs and a weight of 150 lbs at three-months postpartum, would have retained 107% of her pre-pregnancy weight [(150/140) * 100 = 107%].

Weight loss at three-months postpartum, as a percent of gestational weight gain lost by three months postpartum was calculated as: weight loss = (last recorded weight before delivery – weight at three-months postpartum / last recorded weight before delivery – pre-pregnancy weight) * 100. A value of 100% would indicate that a women lost 100% of the weight that she gained during pregnancy, a value less than 100% would indicate the women still had weight to lose to return to her pre-pregnancy weight and a value greater than 100% would indicate the women lost more weight than she gained during pregnancy. For example If a women's pre-pregnancy weight was 140 lbs., her last recorded weight before delivery was 170 lbs., and her weight at three-months postpartum was 150 lbs. she would have lost 67% of the weight that she gained during pregnancy [(170-150)/(170-140) * 100 = 67%].

To meet the recommendations for physical activity in a single trimester of pregnancy or at the postpartum measure, a woman must have completed 30 minutes or more of MVPA (according to accelerometer) for four or more days during each data collection period. To meet the recommendations overall in pregnancy, a woman must have met the recommended 30 minutes or more of MVPA/day for four or more days during each data collection period.

Preliminary Analysis

A number of preliminary analyses were performed. First we determined the maximum number of data points that could be included in the analysis based on hours of wear-time. Second we determined if the cut-points chosen for categorizing physical activity were realistic and analyzable. Third we determined if there was difference in accelerometer wear-time between normal weight women and overweight/obese women. Fourth to determine if the amount of accelerometer wear-time impacted the number of minutes participants spent performing MVPA each day. Finally we analyzed data adjusting for accelerometer wear-time so that we could compare these results to the results obtained without adjusting for accelerometer wear-time.

Using Swartz and Troiano Cut-Points

Data obtained from accelerometers was used to report intensity (sedentary, light, moderate, or vigorous) of physical activity based on counts per minute. Initially we planned to calculate intensity of physical activity with algorithms derived by Swartz, 2000 and Troiano, 2008 as used previously to characterize physical activity during pregnancy in a cross-sectional study (Evenson, 2011). After conducting our initial analyses we determined that the amount of time that women spent performing MVPA determined using the Swartz cut points significantly exceeded all established recommendations to a point that this data became unrealistic (e.g., women spent an average of 222 ± 7.9 minutes/day preforming MVPA) and not useful as each participant would have met the physical activity recommendation at each time point studied (1, 26, 92). For this reason we decided not to analyze the Swartz data further, however, for the sake of being complete we included the physical activity data generated using the Swartz cut-points in Appendix B. All remaining analyses of physical activity were conducted using Troiano cut-points, only and are reported in the main portion of this thesis (91).

Decision to Adjust Daily Physical Activity to a Standardized Amount of Accelerometer Wear-Time

Women were asked to wear their accelerometer from the time they woke up until the time they went to bed. The amount of time each woman wore the accelerometer each day was highly variable both within participants and between participants. For example some women wore their accelerometer for as little as 387 minutes/day, while others wore the device for as long as 1440 minutes/day. To determine whether or not this variation in accelerometer wear-time influenced the amount of time the women spent performing MVPA we did two things. First, we determined if weight status, based on pre-pregnancy BMI, influenced accelerometer wear-time. Women in the normal weight group wore the accelerometer on average 745.8 ± 57.3 minutes/day and women in the overweight/obese group wore the accelerometer on average 778.9 ± 120.1 minutes/day. Using an unpaired t-test we determined that weight status did not significantly influence mean accelerometer wear-time (p=0.77). Secondly, we determined if accelerometer wear-time influenced the amount of MVPA performed. We determined that women who wore the accelerometer for at least 6 hours but less than 12 hours per day performed on average 27.5 ± 15.3 minutes of MVPA per day. Women who wore the accelerometer for more than 12 hours per day performed on average 39.4 ± 15.4 minutes of MVPA per day. Based on an unpaired t-test the difference in mean MVPA was not significantly different (p=0.36).

Because there were no significant differences in the mean amount of time that accelerometers were worn by normal weight and overweight/obese women and because accelerometer wear-time did not influence the mean amount of time spent performing MVPA we decided to report our data as it was collected, unadjusted for accelerometer wear-time. Data that was derived based on adjusted accelerometer wear-time of 720 minutes per day is included in Appendix C.

Confidentiality

All data collected as a result of participation in the PEN study was kept completely confidential. Participants were assigned unique identification numbers, and their names were removed from all data collection documents. Forms and participant identification were kept in a locked filing cabinet in the OHSU Hatfield Research Building. Study data and participant information was managed using REDCap, and only those study staff with assigned passwords are permitted to access participant data. REDCap is a secure, web application designed to support data capture for research studies, providing web-based case report forms, real-time data entry validation, audit trials, and a de-identified data export mechanism to common statistical programs. REDCap was developed by a multi-institutional consortium, including OHSU, and was initiated at Vanderbilt University. The system is protected by a login and Secure Sockets Layer (SSL) encryption. Information obtained from the participants' electronic medical records was optically scanned, and typed into REDCap. Data files not appropriate for REDCap (such as the accelerometer documents) were stored on a secure server; the password protected, HPSM Division OHSU network drive, and was only available to research staff performing study related analyses.

CHAPTER 4 RESULTS

Accelerometer data from participants in the OHSU Pregnancy, Exercise & Nutrition (PEN) feasibility study during the first, second, and third trimesters and at three-months postpartum was examined. This research was conducted to accomplish the following specific aims. First, we describe patterns of daily activity including duration and intensity of activity and whether participants met or did not meet physical activity recommendations (30 minutes or more of MVPA on 4 or more days of the week) during and after pregnancy. Then we compared the type and amount of physical activity performed during and after pregnancy by normal weight (BMI <25 kg/m^2) and overweight/obese (BMI ≥ 25 kg/m^2) women and by those who met or exceeded the IOM gestational weight gain recommendations. Finally, we evaluated the relationship between physical activity, maternal weight retention and return to pre-pregnancy weight at three-months postpartum. Our goal was to add to the limited body of research evaluating patterns of physical activity during pregnancy and its impact on maternal and infant outcomes, to provide evidence to support expanded physical activity recommendations and to emphasize the importance of physical activity in a healthy pregnancy, and to inform future interventions.

Characteristics of Women who completed the Physical Activity Component of the Pregnancy Exercise & Nutrition (PEN) Study

The selection process for inclusion of participants in the longitudinal analysis of physical activity during and after pregnancy is illustrated in Figure 7. Thirty women were enrolled in the PEN study. Two participants withdrew during the first trimester due to time constraints, and were not replaced. The remaining 28 participants were provided accelerometers at four data collection time points of the study: during the first, second, and third trimesters of pregnancy and at three-months postpartum. For this secondary analysis one participant was excluded due to accelerometer wear-time non-compliance at more than two of the four time points; specifically, the accelerometer malfunctioned during the second trimester and the participant did not wear the accelerometer long enough to meet the established wear-time criteria during the third trimester. After this exclusion, data from 27 women qualified for analysis. During the prenatal period 23 participants provided data during all three trimesters of pregnancy. In addition, during the first and second trimesters of pregnancy, three additional women provided wear-time compliant data for a total of 26 sets of physical activity data. During the third trimester two additional women provided wear-time compliant accelerometer data for a total of 25 sets of physical activity data. In the postpartum period, 25 participants provided wear-time compliant data and were included in the analysis; two participants were excluded for not meeting the accelerometer wear-time criteria.

Characteristics of the 27 participants included in this physical activity analysis are illustrated in Table 5. Participants were 27 – 37 years of age, and 24 (89%) were white. It was the first pregnancy for 17 (63%), the second pregnancy for 8 (30%), and the third pregnancy for 2 (7%) of the participants. Sixty percent had earned a graduate degree,

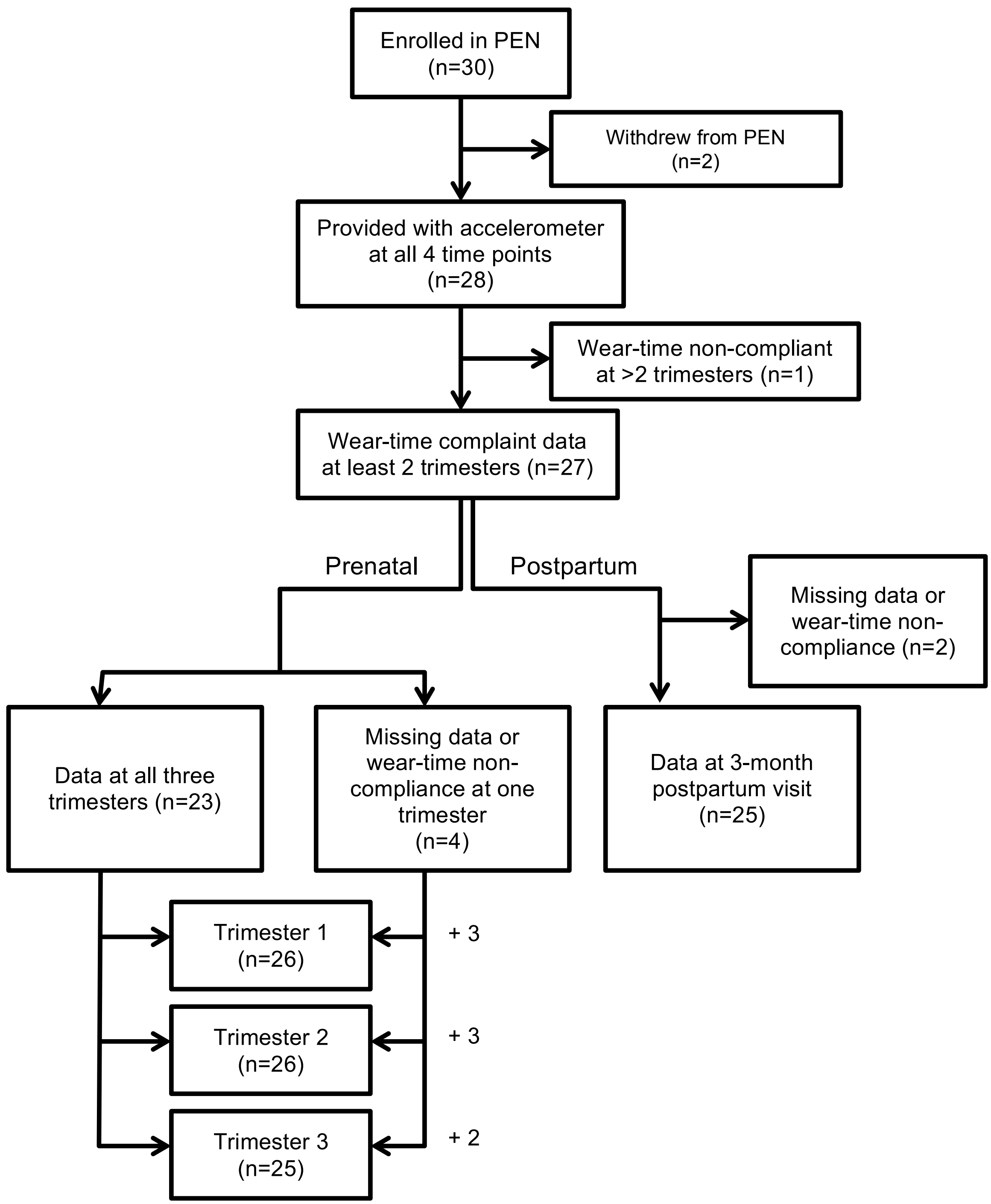

Figure 7. Selection process for participant data to be included in the physical activity analysis of the PEN feasibility study

Table 5. Maternal Demographic Characteristics (n=27)

Age (Years)	
25-29	4 (15%)*
30-34	14 (52%)
35-39	9 (33%)
Race (White)	24 (89%)
Parity	
0	17 (63%)
1	8 (30%)
2	2 (7%)
Education	
2 Year College Degree	2 (7%)
4 Year College Degree	9 (33%)
Graduate Degree	16 (60%)
Employment Status	
Unemployed	1 (4%)
Part-Time Employment	4 (15%)
Full-Time Employment	22 (81%)
Household Income**	
$25,000-$74,999	6 (23%)
$75,000-$149,999	16 (62%)
More than $150,000	4 (15%)
Number of People in Household	
1	1 (4%)
2	13 (48%)
3	7 (26%)
4	2 (7%)
5	1 (4%)

* Number (percent)

** n=26

22 (81%) were employed full-time, and 20 (77%) had a household income of at least $75,000.

Maternal Body Weight and Weight Status

Table 6 summarizes anthropometric characteristics of all 27 participants combined and for participants grouped by pre-pregnancy weight status (normal weight and overweight/obese), and whether they met or exceeded the Institute of Medicine (IOM) recommendations for weight gain during pregnancy based on their pre-pregnancy BMI (21). The mean ± SD (from this point forward results imply SD unless otherwise indicated) pre-pregnancy weight and BMI for all participants was 67.4 ± 12.1 kg and 25 ± 3.6 kg/m^2, respectively. On average, women gained 16.1 ± 5.4 kg or 124% of the amount of weight recommended by the Institute of Medicine (IOM) (21). At three-months postpartum women weighted an average of 107 ± 6.0% of their pre-pregnancy weight and had lost an average of 11.1 ± 2.7 kg or 79% of the weight they gained during gestation.

Of the 27 women included in the analysis, 14 (52%) were classified as normal weight and 13 (48%) as overweight/obese based on pre-pregnancy BMI. Eleven women (41%) remained within or below the IOM gestational weight gain recommendations, and 16 women (59%) exceeded the weight gain recommendations (21). Among women in the overweight/obese group, 12 (92%) exceeded the weight gain recommendations compared to 5 (37%) participants in the normal weight group. Women who exceeded the IOM gestational weight gain recommendation had a significantly higher average pre-pregnancy BMI and average weight at each trimester of pregnancy, higher average weight at three-months postpartum and significantly higher weight retention, as a percent of pre-pregnancy weight, at three-months postpartum compared to women who were within, or below the IOM weight gain recommendation.

There was no significant difference in mean amount of weight lost by three-months postpartum between women in the normal weight and overweight/obese groups. Nor did women who exceeded the weight gain recommendations lose more weight on average by three-months postpartum than those who remained within or below the recommendations. However, when weight loss was evaluated as a percent of gestational weight gain, the differences between groups were significantly lower among overweight/obese women than normal weight women and higher among women who exceeded gestational weight gain recommendations than those who remained within or below the recommendations. It is important to note that these differences are strongly influenced by one participant who was overweight/obese but who only gained 2.7 kg during pregnancy and who lost 9.25 kg during the postpartum period, or 333% of her gestational weight gain.

Table 6. Maternal Anthropometric Characteristics*

	All women (n=27)	Normal weight (BMI<25 kg/m^2)† (n= 14)	Overweight/ Obese (BMI ≥25 kg/m^2)† (n=13)	Within weight gain recommendation‡ (n=11)	Exceeded weight gain recommendation‡ (n=16)
Maternal pre-pregnancy weight (kg)	67.4 ± 12.1 (45.5–97.3)	59.3 ± 6.7 (45.5–70.5)	76.1 ± 10.5§ (56.8–97.3)	60.4 ± 5.3 (50.9–68.6)	72.2 ± 13.27¶ (45.5–97.3)
Maternal pre-pregnancy BMI (kg/m^2)	25 ± 3.6 (18.9–35.1)	22 ± 1.3 (18.9–24.0)	28 ± 2.7§ (25.1–35.1)	22 ± 1.8 (18.9–25.1)	27 ± 3.8¶ (20.9–35.1)
1st trimester weight (kg)	69.3 ± 13.0 (48.7–99.1)	60.6 ± 6.8 (48.7–73.1)	78.7 ± 11.4§ (56.8–99.1)	61.4 ± 5.4 (52.8–69.3)	74.8 ± 14¶ (48.7–99.1)
2nd trimester weight (kg)	75.3 ± 13.7 (55.6–105.0)	66.4 ± 6.7 (55.6–79.5)	84.8 ± 12.9§ (55.6–105.0)	66.4 ± 6.3 (55.9–74.8)	81.4 ± 14.1¶ (55.6–105.0)
3rd trimester weight (kg)	79.5 ± 14.1 (57.7–109)	70.7 ± 8.1 (57.7–84.8)	89 ± 13.1§ (57.9–109.0)	69.9 ± 6.1 (57.9–76.0)	86.2 ± 14.3¶ (57.7–109.0)
Last recorded weight before delivery (kg)	83.5 ± 14.5 (59.6–113.4)	74.9 ± 7.7 (63.1–91.6)	92.7 ± 14.6§ (59.6–113.4)	71.8 ± 5.7 (59.6–77.6)	91.6 ± 13.2¶ (67.1–113.4)
Gestational weight gain (% of IOM recommendation)	124 ± 54 (26–252)	99 ± 28 (63–157)	151 ± 61.5§ (26–252)	75 ± 21 (26–96)	159 ± 40¶ (105–252)
Duration of gestation (weeks)	39.5 ± 2.1 (33.1–42.0)	39.9 ± 1.4 (37.7–42.0)	39.1 ± 2.6 (33.1–41.6)	38.9 ± 2.3 (33.1–41.3)	39.9 ± 1.9 (35.6–42.0)
Weight at three-months postpartum (kg)	72.4 ± 13.8 (50.4–102.4)	63.7 ± 7.1 (53.1–80.9)	81.7 ± 13.3§ (50.3–102.4)	62 ± 5.9 (50.4–70.3)	79.5 ± 13.2¶ (53.1–102.4)
Weight at three-months postpartum (% pre-pregnancy weight)	107 ± 6.0 (88.6–118.0)	108 ± 6 (102–118)	107 ± 6.7 (89–117)	103 ± 5 (89–109)	110 ± 4¶ (105–118)
Weight loss by three-months postpartum (kg)	11.1 ± 2.7 (5.1–17.5)	11.2 ± 10.7 (7.2–17.5)	11.0 ± 2.8 (5.1–15.0)	9.8 ± 2.4 (5.1–13.5)	12.1 ± 2.6 (8.1–17.5)
Weight loss (% gestational weight gain)	79.0 ± 52.2 (45.5 – 332.7)	73.6 ± 13.7 (45.5 – 95.5)	84.8 ± 75.0§ (47.6 – 332.7)	102.7 ± 76.7 (69.2 – 332.7)	62.7 ± 10.2¶ (45.5 – 78.7)

* Mean ± SD (range)

† Self-reported pre-pregnancy weight

‡ Based on 2009 Institute of Medicine Pregnancy Weight Gain Recommendations, using the upper limit for weight gain

§ Significantly different from normal weight women (p-value <0.05)

¶ Significantly different from women who met the weight gain recommendations (p-value <0.05)

Days of Accelerometer Wear-Time

Women were asked to wear the accelerometer from the time they woke up until the time they went to bed for a total of 7 days at each trimester of pregnancy and again at three-months postpartum. During pregnancy, regardless of trimester of gestation, the average number of days in which women met the accelerometer wear-time criteria of ≥ 360 minutes/day was 6.3 ± 0.3 days, the median number of days was 7, and the range was between 4 and 7. During the postpartum period, the average number of days in which women met the wear-time criteria was 5.8 ± 1.1 days, the median number of days was 6, and the range was 4-7 days. The number of days the accelerometer was worn was not impacted by pre-pregnancy weight status as previously described in the Methods section.

Physical Activity Performed by Women During each Trimester of Pregnancy and at Three-Months Postpartum

The first aim of this study was to describe the type and amount physical activity performed by women during and after pregnancy. Table 7 summarizes the average amount of time that women wore their accelerometers among those who met the accelerometer wear-time compliance criteria of at least 360 minutes per day. Mean accelerometer wear-time increased throughout pregnancy from 752 ± 96 minutes/day in the first trimester to 780 ± 118 minutes/day in the third trimester. Average accelerometer wear-time at three-months postpartum was lower, at 739 ± 96.5 minutes/day, than at any trimester during pregnancy. Table 7 also describes the average counts per minute (cpm), and average metabolic equivalents of task (METs) during and after pregnancy. These variables reflect the overall intensity of activity performed.

Despite an increase in accelerometer wear-time throughout pregnancy, the mean cpm and METs decrease over time, which reflect decreased intensity of activity throughout pregnancy.

Description of Physical Activity by Intensity Level

The mean amount of time spent performing light intensity activity increased from 721 ± 95.5 during the first trimester to 755 ± 115.3 during the third trimester. The amount of time women spent in moderate activity decreased from 32 ± 16.6 minutes/day in the first trimester to 24 ± 17.0 minutes/day in the third trimester, and moderate activity decreased further to 20 ± 12.4 minutes/day at three-months postpartum. The amount of time women spent in vigorous activity decreased from 2.0 ± 4.1 minutes/day in the first trimester to less than one minute/day in third trimester. At three-months postpartum the average amount of time spent performing vigorous activity increased to 1.6 ± 2.9 minutes/day. The percent of days during which women performed no vigorous activity ranged from 82-95% for all participants at all time points. The average amount of time spent in MVPA decreased as women progressed through pregnancy and was even lower at three-month postpartum. During the first trimester women spent an average of 34 ± 18 minutes/day or 4.6% of accelerometer wear-time performing MVPA. Whereas at three-months postpartum women only spent 21 ± 14 minutes/day or 2.9% of total accelerometer wear-time performing MVPA.

Table 7. Accelerometer wear-time, physical activity intensity and number of women who met the physical activity recommendations during and after pregnancy *

	1st Trimester (n=26)	2nd Trimester (n=26)	3rd Trimester (n=25)	Postpartum (n=25)
Accelerometer wear-time & overall physical activity intensity				
Wear-time (minutes/day)	752 ± 95.7 (541 – 961)	771 ± 93.2 (589 – 1123)	780 ± 118 (608 – 1236)	739 ± 96.5 (599 – 937)
Counts per minute (cpm)	614 ± 143 (296 – 930)	557 ± 112 (368 – 768)	529 ± 153 (328 – 871)	568 ± 149 (335 – 893)
Metabolic Equivalents of Task (METs)	1.20 ± 0.12 (1.03 – 1.53)	1.17 ± 0.10 (1.03 – 1.38)	1.16 ± 0.10 (1.04 – 1.39)	1.13 ± 0.09 (1.03 – 1.34)
Physical activity intensity				
Light (minutes/day)	721 ± 95.3 (518 – 930)	744 ± 92.9 (552 – 1074)	755 ± 115.3 (579 – 1187)	718 ± 98.6 (553 – 927)
Moderate (minutes/day)	32 ± 16.6 (7 – 80)	26 ± 15.6 (3 – 62)	24 ± 17.0 (3 – 64)	20 ± 12.4 (3 – 39)
Vigorous (minutes/day)	2.0 ± 4.1 (0 – 16)	0.6 ± 2.8 (0 – 15)	0.7 ± 2.5 (0 – 12)	1.6 ± 2.9 (0 –11)
MVPA† (minutes/day)	34 ± 18.2 (7 – 83)	27 ± 16.1 (3 – 62)	25 ± 17.8 (3 – 68)	21 ± 14.0 (3 – 45)
MVPA (% total wear-time)	4.6 ± 2.6	3.5 ± 2.1	3.2 ± 2.3	2.9 ± 2.1
Number of women meeting physical activity recommendations				
Days meeting physical activity recommendation† [mean, median (range)]	3.2 ± 2.2 4 (0 – 7)	2.3 ± 1.9 3 (0 – 6)	1.8 ± 2.0 3 (0 – 6)	1.4 ± 1.6 3 (0-4)
Women who met PEN physical activity recommendation (≥ 30 minutes/day MVPA for ≥ 4 days) [#, (%)	11 (41%)	6 (23%)	7 (28%)	5 (20%)
Women who met CDC physical activity recommendation (≥ 150 minutes/week of MVPA) [#, (%)]	16 (59%)	16 (62%)	10 (40%)	9 (36%)

* Mean ± SD (range), percent of total
† MVPA: Moderate to vigorous physical activity

Number of Women Meeting the Physical Activity Recommendations

For this analysis, meeting the physical activity recommendations was defined as performing ≥ 30 minutes/day of MVPA for ≥ 4 days per week. As illustrated in Table 7 during the first trimester 11 (41%) women met this physical activity recommendation, during the second trimester 6 (23%) women met the physical activity, and during the third trimester 7 (28%) women met the physical activity recommendation. For comparison purposes we also analyzed the data to determine the number of participants who met the Centers for Disease Control (CDC) physical activity recommendation of ≥ 150 minutes/week of MVPA. In the first trimester, 16 (59%) of participants met the CDC recommendation; 16 (62%), and 10 (40%) met the CDC recommendation in the second the third trimesters, respectively. These results shows that more women met the CDC physical activity recommendations than the PEN physical activity recommendations, which differ primarily by the number of days in a week that that MVPA must be performed.

Comparison of Physical Activity Performed by Normal Weight and Overweight/Obese Women During and After Pregnancy

The second aim of this study was to compare the amount of MVPA physical activity performed by normal weight (BMI 18.9 - 25 kg/m^2) and overweight/obese (BMI ≥ 25 kg/m^2) women during the first, second, and third trimesters of pregnancy, at 3 months postpartum, and overall. Table 8 and Figure 7 present summary data of physical activity for normal weight and overweight/obese women during each trimester of pregnancy and at three-months postpartum. Overweight/obese women wore the accelerometer for more time on average than normal weight women, a finding due in part to one woman who wore the accelerometer for an extended amount of time (e.g., 1440 minutes per day) including non-waking hours. Normal weight women had higher average cpm during each trimester, which suggests an overall higher intensity of activity, which is consistent with the higher average number of METs achieved through out pregnancy.

On average, overweight/obese women spent more time (768 minutes/day) performing light intensity activity than normal weight women (715 minutes/day) (Figure 8, A). This observation may reflect the higher average accelerometer wear-time of women in the overweight/obese group. During each trimester of pregnancy the average amount of moderate intensity activity was higher among normal weight women than overweight/obese women (Figure 8, B). The average amount of time associated with vigorous activity was minimal in both groups (Figure 8, C). In the first trimester, overweight/obese women engaged in 61% as much MVPA as normal weight women (Figure 8, D). This difference between groups was significant (p=0.009): overweight/obese women spent an average of 26 minutes/day performing MVPA (95% CI: 19.3 – 34.9) or 3.3% of total accelerometer wear-time, compared to normal weight women who spent 43 minutes/day performing MVPA (95% CI: 32.4 – 54.3) or 5.7% of total accelerometer wear-time. In the second trimester of pregnancy, overweight/obese women engaged in fewer minutes of MVPA than normal weight women and this difference approached significance (p=0.056).

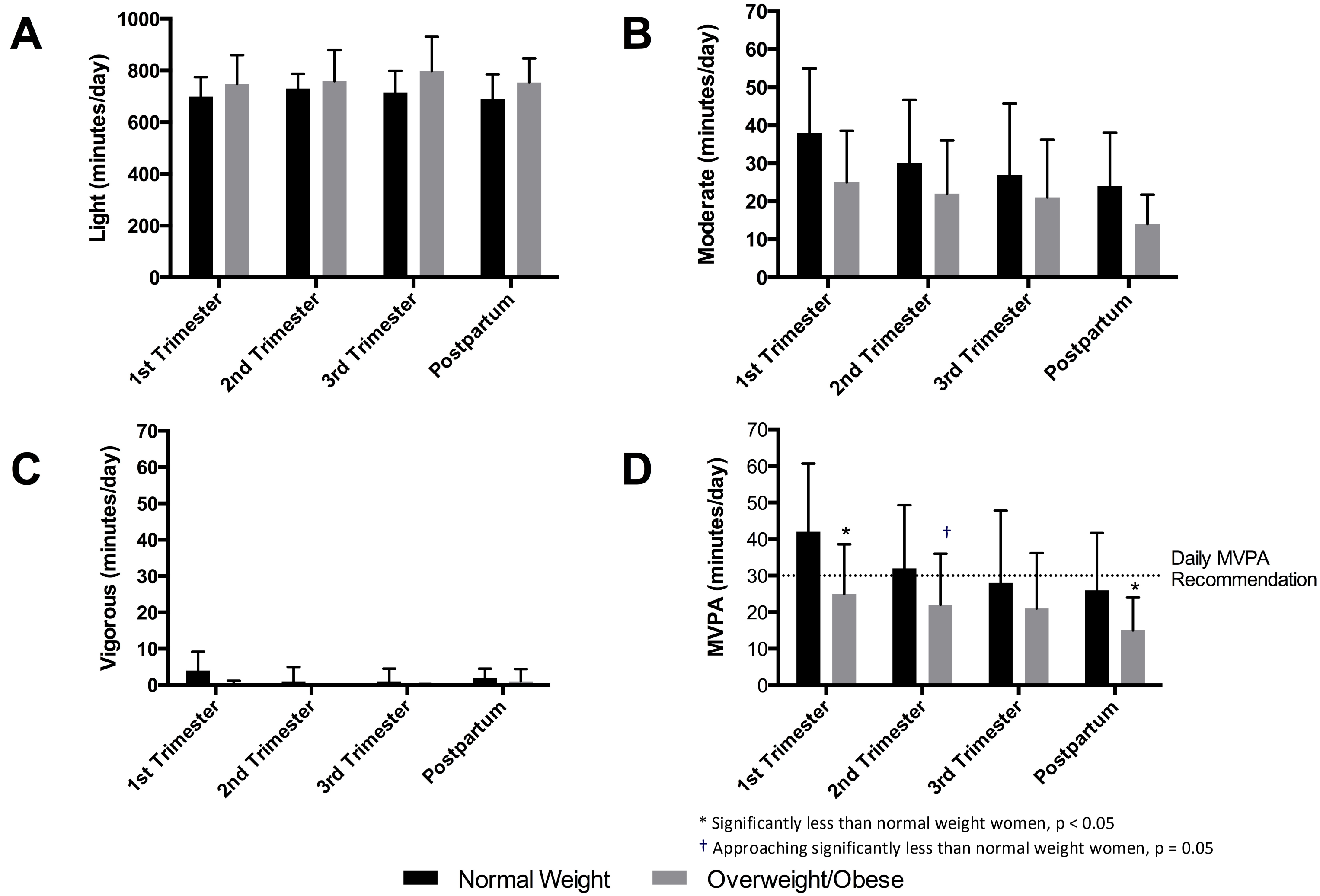

Figure 8. Minutes of light, moderate, vigorous, and total MVPA during each trimester of pregnancy and at three-months postpartum

Table 8. Accelerometer wear-time, counts per minute, metabolic equivalents of task, and time spent performing physical activity of various intensities during each trimester of pregnancy and at three-months postpartum for normal weight and overweight/obese women*

	1st Trimester (Baseline)		2nd Trimester		3rd Trimester		Postpartum	
	Normal Weight (n= 14)	Overweight/ Obese (n=12)	Normal Weight (n=13)	Overweight/ Obese (n=13)	Normal Weight (n=13)	Overweight/ Obese (n=12)	Normal Weight (n=14)	Overweight/ Obese (n=11)
Wear-time (minutes/day)	734 ± 79.1 (564 – 845)	773 ± 111 (541 – 961)	761 ± 53.1 (675 – 838)	781 ± 122 (589 – 1123)	744 ± 83.8 (608 – 843)	819 ± 139 (710 – 1236)	715 ± 90.5 (599 – 937)	770 ± 99.1 (619 – 900)
Counts per minute (cpm)	634 ± 162 (358 – 930)	591 ± 118 (290 – 720)	567 ± 130 (368 – 768)	546 ± 95.2 (436 – 746)	555 ± 172 (346 – 871)	501 ± 126 (328 – 734)	599 ± 173 (335 – 893)	529 ± 105 (368 – 666)
Metabolic Equivalents of Task (METs)	1.23 ± 0.13 (1.53 – 1.20)	1.17 ± 0.09 (1.03 – 1.33)	1.18 ± 0.11 (1.03 – 1.38)	1.15 ± 0.1 (1.05 – 1.31)	1.18 ± 0.12 (1.04 – 1.39)	1.14 ± 0.08 (1.04 – 1.28)	1.16 ± 0.10 (1.03 – 1.34)	1.11 ± 0.05 (1.03 – 1.21)
Physical activity (Troiano cut-points)								
Light (minutes/day)	699 ± 75.6 (549 – 811)	748 ± 111 (518 – 930)	730 ± 56.8 (629 – 795)	759 ± 119 (552 – 1074)	715 ± 83.6 (579 – 818)	798 ± 132 (700 – 1187)	689 ± 96.2 (553 – 927)	754 ± 93.0 (625 – 883)
Moderate (minutes/day)	38 ± 16.9 (15 – 80)	25 ± 13.5 (7 – 54)	30 ± 16.7 (3 – 62)	22 ± 14.0 (4 – 48)	27 ± 18.7 (3 – 64)	21 ± 15.2 (4 – 48)	24 ± 14.0 (3 – 39)	14 ± 7.7 (4 – 24)
Vigorous (minutes/day)	4 ± 5.2 (0 – 16)	0.3 ± 0.9 (0 – 3)	1 ± 4.0 (0 – 15)	0 ± 0.1 (0 -0)	1 ± 3.5 (0 – 12)	0 ± 0.3 (0 – 1)	2 ± 2.5 (0 – 6)	1 ± 3.4 (0 – 11)
MVPA† (minutes/day)	43 ± 18.7 (15 – 83)	26 ± 13.6‡ (7 – 54)	33 ± 17.3 (3 – 62)	22 ± 14.0§ (4 – 48)	30 ± 19.8 (3 – 68)	20 ± 15.2 (4 – 48)	26 ± 15.7 (3 – 45)	15 ± 9.0‡ (4 – 30)
MVPA (% total wear-time)	5.7 ± 2.6	3.3 ± 1.9	4.2 ± 2.3	2.9 ± 1.8	3.8 ± 2.7	2.5 ± 1.7	3.7 ± 2.4	1.9 ± 1.0
Days meeting physical activity recommendation† [mean, median (range)]	4.2 ± 1.9 5 (1 – 7)	2.1 ± 1.9 3 (0 – 5)	3 ± 2.1 3 (0 – 6)	1.5 ± 1.6 3 (0 – 6)	2.3 ± 2.0 3 (0 – 5)	1.5 ± 2.0 2 (0 – 6)	1.8 ± 1.8 4 (0 – 4)	1.1 ± 1.4 2 (0 – 4)
Women who met PEN physical activity recommendations (≥ 30 minutes/day of MVPA for ≥ 4 days) [#, (%)]	9 (64%)	2 (17%)	5 (38%)	1 (8%)	5 (36%)	2 (17%)	5 (36%)	0 (0%)
Women who met CDC physical activity recommendations (≥ 150 minutes/week of MVPA) [#, (%)]	11 (79%)	5 (42%)	9 (69%)	7 (54%)	7 (54%)	3 (25%)	7 (50%)	2 (18%)

* Mean ± SD (range), percent of total

† MVPA: Moderate to vigorous physical activity

‡ Significantly different from normal weight women, corresponding means and 95% confidence intervals, first trimester: 42 (34.1 – 53.7), 26 (19.3 – 34.9) p= 0.009; postpartum: 26 (19.0 – 36.5), 15 (10.5 – 20.6) p= 0.015

§ Approached significant difference from normal weight women, corresponding means and 95% confidence intervals, second trimester: 33 (25.5 – 43.5), 22 (16.0 – 30.6) p = 0.056

Overweight/obese women averaged 22 minutes of MVPA (95% CI: 16.0 – 30.6) in the second trimester, which was 65% as much activity as normal weight women who performed an average of 33 minutes of MVPA (95% CI: 25.5 – 43.5). In the third trimester normal weight women did not engage in significantly more MVPA than overweight/obese women (p= 0.209). Overweight/obese women averaged 20 minutes (95% CI: 12.9 – 32.0) in MVPA, which was 59% as much activity as normal weight women who spent 30 minutes (95% CI: 20.4 – 42.7) in MVPA. At three-months postpartum overweight/obese women engaged in significantly fewer minutes of MVPA than normal weight women (p=0.015). Overweight/obese women averaged 15 minutes (95% CI: 10.5 – 20.6) in MVPA, which was 58% as much as normal weight women who spent 26 minutes (95% CI: 19.0 – 36.5) in MVPA.

Overall physical activity during pregnancy was significantly different between normal weight and overweight/obese women (p=0.004) (Appendix A). Normal weight women averaged 34 ± 19 minutes of MVPA per day overall in pregnancy. Overweight/obese women averaged 23 ± 14 minutes of MVPA per day overall in pregnancy. This shows that although there was no difference in physical activity between the two groups in the second and third trimesters, when taken together, pre-pregnancy weight status was associated with physical activity overall in pregnancy.

As illustrated in Figure 9, the number of normal weight women who met the recommendation of ≥ 30 minutes/day of MVPA for ≥ 4 days/week, during the first, second, and third trimesters was, 9 (64%), 5 (38%), and 5 (36%), respectively (111). The number of overweight or obese women who met the physical activity recommendation of ≥ 30 minutes/day for ≥ 4 days/week in the first, second, and third trimesters and at three-months postpartum was, 2 (17%), 1 (8%), and 2 (17%) women, respectively. During the postpartum period, of the 5 women who met the physical activity recommendation of ≥ 30 minutes/day of MVPA for ≥ 4 days per week, all were normal weight based on pre-pregnancy BMI. Using an alternative physical activity recommendation of ≥ 150 minutes/week of MVPA proposed by the CDC, both normal weight and overweight/obese women met the recommendation more frequently (Table 8). These results show that regardless of weight status, in general, as women progress though pregnancy they perform less MVPA and, as a result, are less likely to meet physical activity recommendations.

Odds of Meeting Physical Activity Recommendations During Pregnancy based on Maternal Pre-Pregnancy Weight Status

The third aim of this study was to determine whether women who were normal weight had greater odds of meeting the physical activity recommendations of ≥ 30 minutes/day of MVPA for ≥ 4 days/week than those who were overweight/obese. We calculated odds ratios to answer this question and the results are presented in Table 9. We determined that women who were normal weight based on pre-pregnancy BMI were 9 times more likely to meet the physical activity recommendations in the first trimester of pregnancy than those who were overweight/obese and this finding was significant ($p=0.014$). In the second and third trimesters of pre-pregnancy, normal weight women were 7.5 and 3.12 times, respectively, as likely to meet the physical activity recommendations as overweight/obese women, however, these odds were not significant.

Table 9. Odds of meeting physical activity recommendations during pregnancy based on maternal pre-pregnancy weight status (normal weight verses overweight/obese)

	Estimated odds ratio	P-value	95% CI
1st Trimester	9.00	0.014	(1.40 – 58.0)
2nd Trimester*	7.50	0.160	(0.61 – 384)
3rd Trimester*	3.12	0.446	(0.36 – 39.4)

*Based on Fisher's exact test

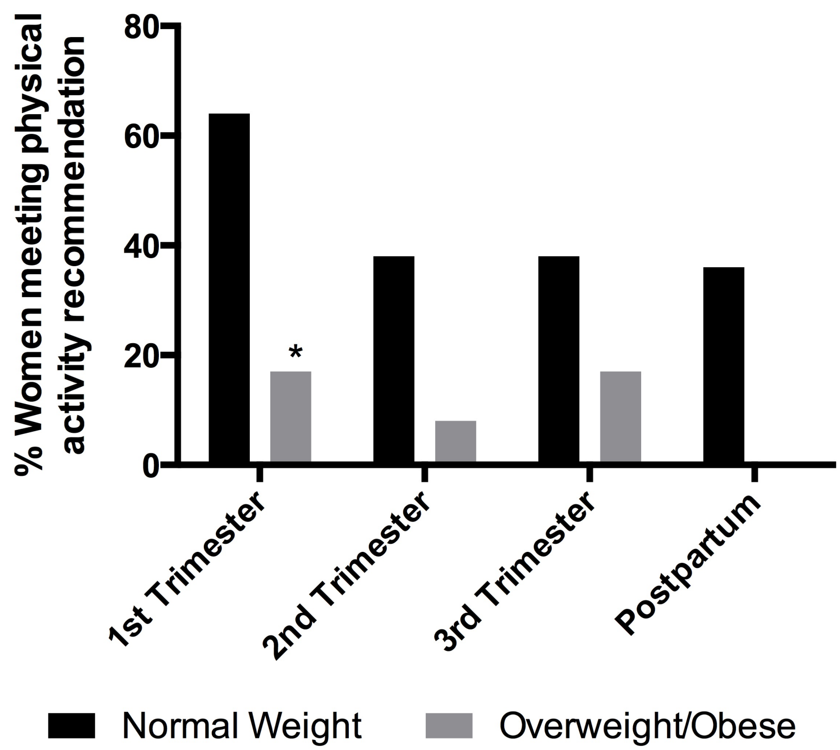

Figure 9. Percent of normal weight and overweight/obese women who met the physical activity recommendations (≥ 30 minutes/day of MVPA for ≥ 4 days/week) during each trimester of pregnancy and at three-months postpartum

Number of Women Meeting the Physical Activity Recommendations based on Meeting or Exceeding the IOM Recommendations for Gestational Weight Gain

Table 10 and Figure 10 show the number and percent of women who met the physical activity recommendations of ≥ 30 minutes/day of MVPA for ≥ 4 days/week based on whether they met or exceeded the IOM gestational weight gain recommendations. Of the 11 women who were within or below the weight gain recommendations, 7 (64%) met the physical activity recommendation during the first trimester, 4 (40%) met the recommendations during the second trimester, and 4 (40%) met the recommendations during the third trimester. Fewer of the 16 women who exceeded the IOM gestational weight gain recommendations met the physical activity recommendation during the first trimester 4 (27%), the second trimester, 2 (13%), and the third trimester, 3 (20%) of pregnancy. At three-months postpartum, 4 (36%) of those who met the weight gain recommendation also met the physical activity recommendation. Of the women who exceeded the IOM gestational weight gain recommendation, only 1 (7%) met the physical activity recommendation after pregnancy.

Table 10. Number of women who met the physical activity recommendations during each trimester of pregnancy and at three-months postpartum based on meeting or exceeding gestational weight gain recommendations*

	Within weight gain recommendations (n=11)	Exceeded weight gain recommendations (n=16)
Trimester 1† **(Baseline)**	7 / 11 (64%)	4 / 15 (27%)
Trimester 2	4 / 10 (40%)	2 / 16 (13%)
Trimester 3	4 / 10 (40%)	3 / 15 (20%)
Postpartum	4 / 11 (36%)	1 / 14 (7%)

* ≥ 30 minutes/day of MVPA for ≥ 4 days

† Number of women meeting physical activity recommendation / number of women who provided data during each time period; number may be lower than total number of women in each group

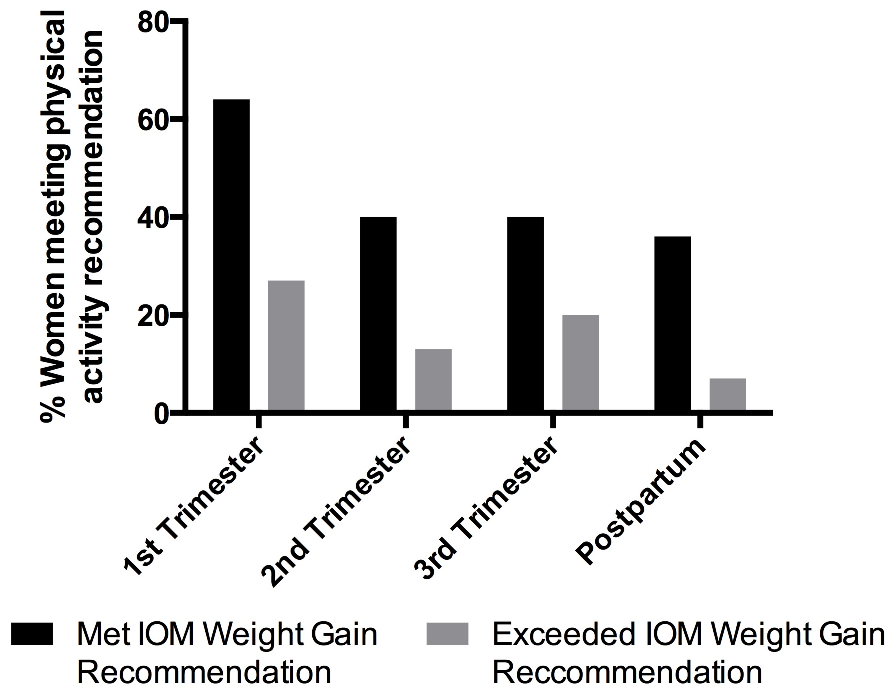

Figure 10. Percent of women who met the physical activity recommendations (≥ 30 minutes/day of MVPA for ≥ 4 days/week) based on meeting or exceeding weight gain recommendations during each trimester of pregnancy and at three-months postpartum

Odds of Meeting or Exceeding the IOM Gestational Weight Gain Recommendations Based on Meeting or Not Meeting the Physical Activity Recommendation

An additional component of the third aim was to determine whether women who met the physical activity recommendation of ≥ 30 minutes/day of MVPA for ≥ 4 days/week during each trimester of pregnancy were more likely to remain within the IOM weight gain recommendations. Odds ratios were used to determine these relationships and the results of the analysis are illustrated in Table 11. We found that meeting the physical activity recommendations at any trimester of pregnancy did not significantly impact the odds of meeting the recommendation for gestational weight gain.

Table 11. Odds of meeting or exceeding the IOM weight gain recommendations based on meeting or not meeting the physical activity recommendation

	Estimated odds ratio	P-value	95% CI
1st Trimester*	4.81	0.138	(0.69 – 35.7)
2nd Trimester*	4.67	0.256	(0.48 – 61.0)
3rd Trimester*	2.67	0.522	(0.32 – 23.7)

*Based on Fisher's exact test

Number of Women Meeting the Physical Activity Recommendation Overall During Pregnancy

The second component to the third aim was to compare gestational weight gain among women who met or did not meet the physical activity recommendation overall, defined as performing at least 30 minutes/day of MVPA for ≥ 4 days/week, during each trimester of pregnancy. Only two participants met the physical activity recommendation during each trimester of pregnancy. Seven participants met the physical activity recommendation two out of three trimesters, and 15 participants met the physical activity recommendation one out of three trimesters. Due to the small number of women who met the physical activity recommendation overall, we were unable to complete this analysis.

However, when we carried out this analysis using the CDC physical activity recommendation of preforming at least of 150 minutes of MVPA per week, 7 participants met this goal throughout pregnancy (Table 12). Women who met the CDC physical activity recommendation overall had an average pre-pregnancy BMI of 24 ± 3.6 kg/m^2 which was not significantly different from those who did not meet the physical activity recommendation overall, 25 ± 3.8 kg/m^2. Of the women who met the physical activity recommendation overall, 5 (71%), had a normal pre-pregnancy weight status. Likewise, there was no difference in mean gestational weight gain between those who met (15 ± 2.5 kg) and those who did not meet the physical activity recommendation overall (17 ± 6.1 kg). Similarly, there was no significant difference between groups in mean gestational weight gain indexed to recommended gestational weight gain. Those women who met the CDC physical activity recommendations overall (n=7) gained 108 ± 3.9% of the recommended amount of weight and those who did not meet the physical activity recommendations overall (n=20) gained 130 ± 58% of the recommendation. We observed that of the 7 women who met the CDC physical activity recommendation overall, 5 (71%) met the IOM gestational weight gain recommendations, of the 20 women who did not meet the CDC physical activity recommendation overall, only 6 (30%) met the IOM recommendation for gestational weight gain. Finally, women who met the CDC physical activity recommendation overall retained significantly less of the weight they gained during pregnancy at three-months postpartum, 104 ± 1.7% than women who did not meet the physical activity recommendations overall, 108 ± 6.7%, (p= 0.03).

Table 12. Number of women meeting the CDC physical activity recommendations of 150 minutes of MVPA per week overall during pregnancy and its impact on gestational weight gain

	Met physical activity recommendations overall* (n=7)	Did not meet physical activity recommendations overall (n=20)
MVPA minutes/week†	306 ± 103 (166 – 578)	139 ± 102‡ (12 – 477)
Maternal pre-pregnancy BMI (kg/m^2)	24.1 ± 3.6 (21.0 – 29.8)	25 ± 3.8 (18.9 – 35.1)
Gestational weight gain (kg)	15.1 ± 2.5 (11.7 – 19.2)	16.5 ± 6.1 (2.78 – 25.9)
Recommended gestational weight gain (%)	109 ± 3.9 (77.7 – 165)	130 ± 58.1 (25.9 – 252)
Women who met the IOM recommendation for weight gain (# [%])	5 (71)	6 (30)
Weight at three-months postpartum (% pre-pregnancy weight)	104 ± 1.7 (102 – 107)	108 ± 6.7 (88.6 – 118)
Weight loss (% gestational weight gain)	80.0 ± 64.3 (45.5 – 333)	78.6 ± 7.6 (70.1 – 90.3)

* ≥ 150 minutes/week of MVPA at all three trimesters of pregnancy

† Mean ± SD, (range)

‡ Significantly different from women who met the physical activity recommendations overall during pregnancy (p-value <0.05)

Association between Postpartum Physical Activity and Postpartum Weight Retention and Weight Loss

Finally we determined the impact of meeting the physical activity recommendation after pregnancy on postpartum weight loss and weight retention. As shown in Figure 11, the mean amount of weight retained at three-months postpartum for women who met the physical activity recommendation was 107 ± 2.75%, compared to 108 ± 1.43% for women who did not meet the physical activity recommendation (p=0.962).

To determine the impact of meeting the physical activity recommendation on postpartum weight loss, the mean amount of weight lost between those who met and those who did not meet physical activity recommendation were compared. The mean amount of weight lost (weight at three-months postpartum – last recorded weight before delivery) was not significantly different (p=0.334) between those who met (9.91 ± 0.82 kg) and those who did not meet (11.25 ± 0.65 kg) the physical activity recommendation at three-months postpartum (data not shown).

Due to the small number of women who met the physical activity recommendation during the postpartum period we determined the association between the amount of time spent performing MVPA and the amount of weight lost (as a percent of the amount of weight gained during pregnancy) (Figure 12). We found no significant difference in the association between the amount of MVPA and the amount of weight lost among women in the normal weight (p=0.332) or the overweight/obese groups. Although not significant, the relationships for both the normal weight and the overweight/obese groups were positive, suggesting that more time spent performing MVPA after pregnancy may aid in return to pre-pregnancy weight.

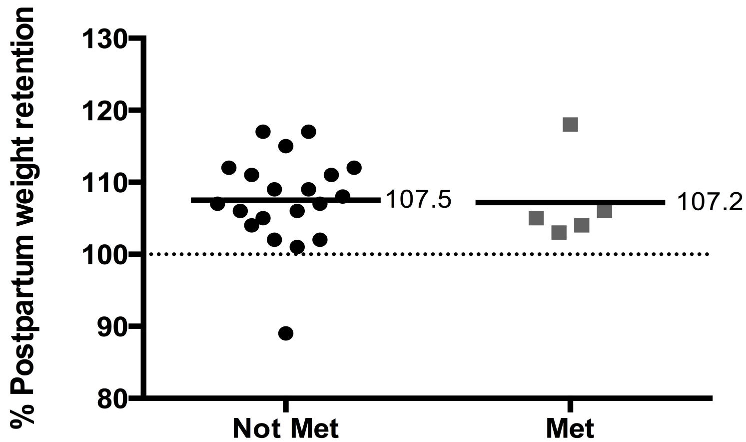

Figure 11. Relationship between meeting (n=5) or not meeting (n=20) the physical activity recommendation and percent postpartum weight retention (p=0.926)

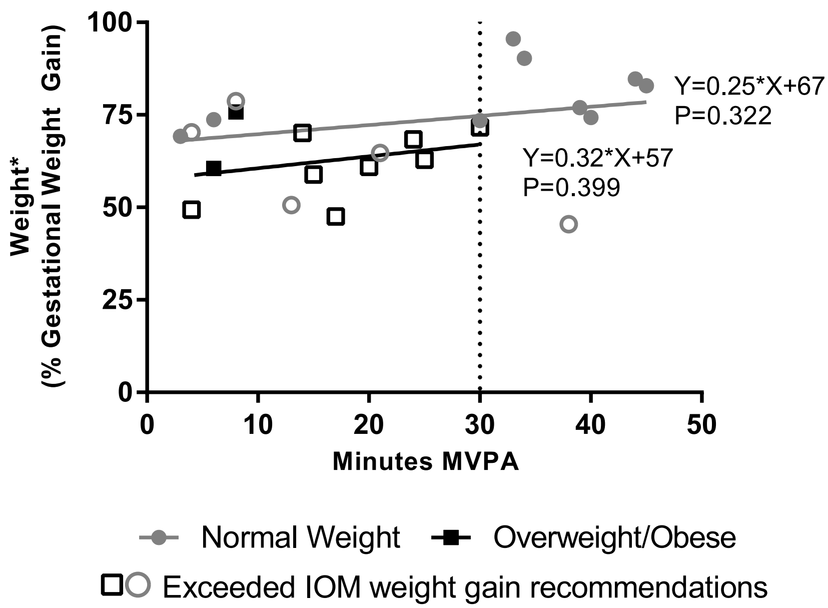

Figure 12. Impact of MVPA minutes on weight loss, as a percent of gestational weight gain between normal weight and overweight/obese women

*One woman lost 233% of the weight she gained during pregnancy and was excluded from this figure

In summary, we found that fewer than 50% of women in the PEN study met the physical activity recommendation of ≥ 30 minutes/day of MVPA for ≥ 4 days/week at any trimester during pregnancy. Only two participants met this recommendation during all three trimesters of pregnancy. Women who were of normal weight status before becoming pregnant performed more minutes of MVPA than overweight/obese women at each trimester of pregnancy and at three-months postpartum. The mean MVPA for some participants was ≥ 30 minutes/day but they did not meet the physical activity recommendation because they did not perform ≥ 30 minutes/day of MVPA at least 4 days/week. In the first trimester of pregnancy, normal weight participants were 9 times more likely (p=0.014) to meet the physical activity recommendation than overweight/obese participants. Women with higher average minutes of MVPA at three-months postpartum lost more of the weight they gained during pregnancy.

CHAPTER 5 DISCUSSION

This study examined the relationship between maternal pre-pregnancy BMI, gestational weight gain, and postpartum weight retention and physical activity level throughout pregnancy in 27 women who participated in the Pregnancy, Exercise, and Nutrition (PEN) feasibility study. The goal of this study was to describe physical activity intensity levels in pregnant women throughout pregnancy and at three-months postpartum. An additional goal was to determine the differences in physical activity levels between pregnant women who were normal weight or overweight/obese and the impact of moderate-to-vigorous physical activity on gestational weight gain and weight retention at three-months postpartum. These findings will be used to enhance the PEN curriculum and to establish a protocol to effectively analyze accelerometer data in pregnant women that will be used in future studies

Participant Demographics

The average age of participants in the PEN study was 32.9 ± 2.9 years, which is higher than the national average of 25.6 years of age when women become pregnant (112). Seventy-eight percent of PEN participants reported an annual household income of $75,000 or greater, which is higher than the national median household income of about $53,000 (2009-2013) (113). Ninety-three percent of PEN participants had at least a 4-year college degree, which is higher than the 28.5% of the US adult population with 4-year college degrees. Finally, 89% of PEN participants were white and non-Hispanic, which is higher than the national percent of 64% as well as the Oregon percent of 77.5% (113). The demographic profile could be due to the fact that the PEN study was carried out in the Pacific Northwest and designed to test a component of a work-place wellness program and, as such, all participants were OHSU employees or spouses of OHSU employees. Thus, results generated from the PEN study may not be generalizable to other populations.

Participant Weight Gain based on Pre-Pregnancy Body Mass Index

Women in our study who exceeded the IOM gestational weight gain recommendations had a significantly higher average pre-pregnancy BMI and higher average weight at each trimester of pregnancy. Five normal weight women exceeded the IOM recommendations for weight gain, whereas nine overweight/obese women exceeded the recommendation (21). These results are consistent with the premise that starting pregnancy at a normal weight is predictive of gaining appropriate weight during pregnancy.

According to the CDC's Pregnancy Risk Assessment Monitoring system (PRAMS) women with a pre-pregnancy BMI in the overweight and obese categories exceeded the IOM gestational weight gain guidelines more often than women in the normal or underweight categories. In a 2015 analysis using the PRAMS 2000-2009 data analyzed maternal weight gain in a sample representative of the United States (114). Gestational weight gain was calculated as the difference between maternal weight at delivery (as reported on birth certificates) and self-reported pre-pregnancy weight. PRAMS found that 35.8% of women gained within the IOM gestational weight gain recommendations, 44.4% gained above, and 19.8% gained below (114). Mean gestational weight gain decreased as pre-pregnancy BMI increased. Normal weight women had the greatest mean gestational weight gain, 15 kg (33.3 pounds) and obese, class III women had the lowest mean gestational weight gain 9.5 kg (20.9 pounds) (114). Underweight and normal weight women had the highest proportion of women who gained within the IOM recommendation for weight gain, whereas overweight and obese women had the smallest proportion of women gaining within the IOM recommended levels (114).

Brawarsky et al. analyzed a longitudinal cohort of 1100 pregnant women in San Francisco, California, USA (115). Using medical records, gestational weight gain was calculated as maternal weight at the last prenatal visit within one week of delivery minus weight prior to pregnancy. Fifty-three percent of participants exceeded gestational weight gain recommendations and women who were overweight prior to becoming pregnant had significantly higher odds of excessive weight gain compared to women with a normal pre-pregnancy weight (OR: 2.26; 95% CI: 1.43 – 3.56) (115). This study differed from PEN in that pre-pregnancy weight was derived from medical records and not by maternal self-report and there was no adjustment of gestational weight gain for week of gestation at delivery. However, similar to these reports, we found that women who exceeded the weight gain recommendations had a significantly higher pre-pregnancy BMI than women who gained within the guidelines.

Objectively Measuring Physical Activity Using Accelerometers

There is a level of inconsistency surrounding cut-point measures in studies that use accelerometers in the pregnant population. Cut-point measures such as Freedson (1998) appear to be used most frequently (95, 101, 104-106, 108, 116). Freedson cut-points are considered the “gold-standard” and have been used routinely for a variety of populations, making them comparable to a number of different studies. We did not analyze data using Freedson cut-points for two reasons. First, we felt that the Freedson cut-points might be elevated for this population and would potentially underestimate time spent performing MVPA. Second, we used the Evenson et al. study as a framework for our analysis, where Troiano and Swartz cut-points were used to analyze accelerometer data (27). Troiano (2008) cut-points, calculated by taking the weighted average of four different previously determined cut-point measures, are also a popular cut-point used in the pregnant population (23, 91, 93, 95, 117, 118). Until recommendations or standardizations of cut-point measures are clarified for use in the pregnant and postpartum population, using two or more measures may prove beneficial for comparisons purposes.

Our initial plan was to analyze accelerometer output using both Troiano (2008) and Swartz (2000) cut-points to determine amount of time spent in various levels of intensity of physical activity. We believed that Swartz cut-points overestimated the amount of moderate intensity activity engaged in and underestimated the amount of light physical activity. Our conclusion is based on the low counts per minute needed to achieve moderate intensity activity level. We found that the output provided using Swartz cut-points were unrealistic and did not appropriately represent the activity level of our study participants during and after pregnancy. For example, using Swartz cut-points, women in our study spent an average of 230 minutes/day performing MVPA during pregnancy. Evenson et al reported similar results in two studies (2012, 2013) where the average amount of time spent performing MVPA was more than 200 minutes per day using the Swartz cut-points (27, 104). Based on these and our own findings we believe that data derived using Swartz cut-points should be interpreted with caution, as results for MVPA are likely overestimated.

Accelerometers have become increasingly popular for objectively measuring physical activity in a variety of populations, including during pregnancy and in the postpartum period. At this point, accelerometers are the most accurate way to measure physical activity intensity levels. Bell et al. used accelerometers to measure physical activity levels in overweight/obese pregnant women and concluded that objective measure of physical activity should be used whenever possible in studies investigating physical activity and pregnancy outcomes. There has been some speculation regarding accelerometer hip placement later in pregnancy and level of accuracy (119). DiNallo et al. assessed women at 20-weeks and 32-weeks of pregnancy to determine changes in accelerometer output (119). These authors suggest that to accurately measure physical activity in this population it is necessary to statistically control for changes in body girth at monitor placement site and monitor tilt to improve the accuracy of output (119). Accelerometer placement site was not controlled for in our analysis.

There is ongoing research related to accuracy of accelerometer placement. Common placement sites are at the hip and wrist. Ellis et al. compared accelerometers worn on the hip and wrist for predicting physical activity and energy expenditure (120). Ellis et al. observed 8 activities and determined that across all activities combined (laundry, window washing, dusting, dishes, sweeping, stairs, walking and running), the hip and wrist worn accelerometers obtained average accuracies of 70.2% and 80.2%, respectively (120). Accuracy was based on predictive models, classification trees, and random forest tests (120). The wrist accelerometer proved more useful in predicting activities with significant arm movement, while the hip accelerometer was superior for predicting locomotion and estimating energy expenditure (120). This is an important consideration to make when creating accelerometer protocols for pregnant women.

Initially we intended to base our analysis on 10 or more hours of accelerometer wear-time for four or more days. However, our preliminary analyses showed that using the criteria of 10 or more hours per day, 4 (14%) additional participants would have been excluded. To maintain our sample size, we reduced the number of hours of wear-time to 6 hours per day (360 minutes). Applying this criterion reduced the number of participants that would have been excluded to 1 or 4% of our total sample. In the literature, the hours of required accelerometer wear-time appear to vary from a minimum of 8 hours to a maximum of 13 hours (101, 105). However in our analysis we determined that accelerometer wear-time did not significantly impact the number of minutes spent preforming MVPA although this conclusion much be interpreted with caution given our small sample size and thus the risk of committing a type II statistical error, e.g., the failure to detect an effect that is actually present.

An alternative means of normalizing accelerometer wear-time across participants is to adjust output based on actual accelerometer wear-time. If minutes spent in each intensity level are adjusted for wear-time, it is generally done by representing minutes as a proportion of total wear-time (107). Specifically this is done by standardizing wear-time to a specific time using weighted models to account for differences in wear-time. Conversely most studies report minutes per day in each intensity level as an absolute value regardless of wear-time (105, 108). To verify whether or not accelerometer wear-time influenced the amount of time the women spent performing MVPA, we determined if weight status, based on pre-pregnancy BMI, influenced accelerometer wear-time and/or if accelerometer wear-time influenced the amount of MVPA performed. For our dataset there was no significant difference in minutes of wear-time and minutes of MVPA when our data was adjusted for wear-time. Additionally, there was no difference in average wear-time between normal weight and overweight/obese women. To ensure completeness of the analysis we analyzed the same data adjusting wear-time to 12 hours per day (720 minutes) (Appendix C). Adjustment to 12 hours per day was chosen after calculating mean and median wear-time of participants at all four time points. Adjusting wear-time to 12-hours per day resulted in small but non-significant differences in time spent in MVPA. Given that time spent in light intensity activity increased during pregnancy, wear-time adjustment may be a useful technique when change in light intensity activity is the primary outcome variable.

Participant Physical Activity During Pregnancy

The duration and intensity of physical activity quantified in this study was consistent with other studies that used accelerometers to measure physical activity in pregnant women. Using Troiano cut-points, we found that women spent 4.4%, 3.9% and 3.5% of total accelerometer wear-time in MVPA during the first, second, and third trimesters of pregnancy, respectively. These numbers are consistent with a number of other studies that used accelerometers to assess physical activity. Specifically, Hayes et al. reported that pregnant women spent 4.8%, 4.3% and 3.0% of total accelerometer wear-time performing MVPA during the first, second, and third trimesters, respectively (105).

Our results are consistent with reports by others in regard to the number of minutes of activity in each intensity category. In the first, second and third trimesters of pregnancy women spent an average of 34, 27, and 25 minutes/day performing MVPA, respectively. These results are consistent with findings by Van Poppel et al. where women in the first, second and third trimesters of pregnancy spent an average of 30.3, 26.1, and 22.7 minutes/day performing MVPA, respectively (108).

A number of studies assessed sedentary behaviors to determine their effect on specific outcomes. To account for sedentary behaviors, specific cut-points and algorithms are used, which differ from those monitoring physical activity intensity. For the purposes of this analysis we grouped sedentary activity with light activity and did not use it as an outcome variable. However, we found that as accelerometer wear-time increased, time spent in light intensity activity also increased. This shows that a more sensitive cut-point measure, designed to interpret sedentary and light physical activity behaviors would be needed to determine a more precise outcome of sedentary and light intensity activity. In future studies sedentary and light activity level may be an important distinction to make to determine if these behaviors are more predictive of weight gain and weight retention than time spent in MVPA.

Pre-Pregnancy Weight Status and Physical activity

Our results show that in the first trimester of pregnancy normal weight women were 9.0 ($p = 0.014$) times more likely to meet the physical activity recommendation as overweight/obese women. During the second and third trimesters normal weight women were 7.5 and 3.1 times more likely to meet the physical activity recommendations than overweight/ obese women, respectively, although these odds were not significant. These results suggest that weight status impacts physical activity patterns early in pregnancy and should be a focus of interventions to enhance maternal and infant outcomes.

Women who were overweight/obese at the start of pregnancy accumulated significantly fewer minutes of MVPA in the first trimester than normal weight women. Overweight/obese women also accumulated fewer minutes of MVPA in the second and third trimesters than women who were normal weight; and these differences approached significance. This again shows the importance of early intervention to increase physical activity during pregnancy, or ideally before the start of pregnancy. A connection can also be made between weight status at the start of pregnancy and gestational weight gain.

Meeting the Physical Activity Recommendation during Pregnancy and at Three-Months Postpartum

The results reported here show that fewer than 50% of women met the physical activity recommendation of 30 minutes or more of MVPA on 4 or more days a week during any trimester of pregnancy or at the postpartum period. The percentage of overweight/obese women who met the physical activity recommendation was considerably lower at all time points than normal weight women. The PEN curriculum used the physical activity recommendation from 2002 American College of Obstetrics and Gynecology (ACOG) to classify participants as meeting or not meeting physical activity recommendations (1). The majority of studies using accelerometer data to evaluate physical activity by pregnant women present data as mean minutes/day (27, 101, 102, 104-107). Reporting mean minutes/day rather than minutes/week is due to wear-time validation allowing for a variable number of necessary accelerometer wear-time days.

For comparison purposes we also evaluated how many participants in the PEN study met the 2008 Centers for Disease Control (CDC) recommendations of an accumulation of at least 150 minutes of MVPA per week (26). Using this definition, the number of women who met the recommendation increased considerably. The CDC recommendation may be more inclusive and representative of the physical activity data, and is also used in accelerometer studies of pregnant women (108, 116). Additionally using this measure may be more comparable to the general population who is also advised to accumulate at least 150 minutes of MVPA per week and to studies that do not use objectively measured physical activity (121). For example, the output generated by most Pregnancy Physical Activity Questionnaires (PPAQ) is often reported in minutes/week (35). When possible both minutes/day and minutes/week of MVPA should be analyzed for comparison and outcome purposes.

Physical Activity and Gestational Weight Gain

We did not find significant connections between meeting physical activity recommendations and meeting the gestational weight gain recommendations. This was likely due to the limited number of participants in general, and the limited number who met the physical activity recommendations, in particular. Our results showed increased likelihood of achieving gestational weight gain within the IOM recommendations for participants who met the physical activity recommendation, but this relationship did not reach statistical significance.

One participant gained less weight than was recommended by the IOM and impacted gestational weight gain results. Particularly because she performed limited MVPA during pregnancy, averaging 8 minutes/day of MVPA throughout pregnancy such that she did not meet the physical activity recommendation at any time point. When this participant was excluded from analysis, the trend showed that as the amount of time spent performing MVPA increased the greater the likelihood of remaining within the IOM recommendations for gestational weight gain, although this trend was not significant.

A meta-analysis by Thangaratinam et al. showed no significant reduction in gestational weight gain in trials evaluating physical activity interventions (122). Thirty-four randomized trials were reviewed to determine the effect of physical activity interventions on weight-related outcomes and found no significant difference between control and intervention groups and their adherence to IOM recommended gestational weight gain (123). Compared with control women, there was a lower weight gain of

1.42 kg with intervention (123). An earlier meta-analysis by Streuling et al. showed that seven trials reported a tread for less gestational weight gain in the exercise group, which was only significant ($p<0.05$) in one of these trials (124). The remaining five trails reported that women in the exercise groups did not gain significantly less weight than their counterparts in control groups (124).

Physical Activity and Postpartum Weight Retention

There was no significant difference in mean amount of weight lost by three-months postpartum between women in the normal weight and overweight/obese groups. Nor did women who exceeded the weight gain recommendations lose more weight on average by three-months postpartum than those who remained within or below the recommendations. However, when weight loss was evaluated as a percent of gestational weight gain, the differences between groups were significantly lower among overweight/obese women than normal weight women and higher among women who exceeded gestational weight gain recommendations than those who remained within or below the recommendations. These results may be influenced by one woman who only gained 2.8 kg during pregnancy and lost 9.3 kg by three-months postpartum.

The IOM reports about 50% of overweight women gain more than 30 pounds during pregnancy and at 6-months postpartum 25% of all women retain more than 20 pounds (21). Returning to a healthy weight after delivery is important to set the stage for healthy future pregnancies (21). In this study, women who spent more time preforming MVPA at three-months postpartum tended to lose more of the weight they gained during their pregnancy. However, none of the overweight/obese women met the physical activity recommendation at three-months postpartum. Participants in this study gained an average of 35.5 ± 11.8 pounds during pregnancy. Of that weight, women retained an average of 11 ± 5.8 pounds at three-months postpartum. Without having access to weights at 6-months postpartum, we were not able to determine if these women returned to their pre-pregnancy weight at this later point.

In a meta-analysis of seventeen studies evaluating pre-pregnancy BMI, gestational weight gain and postpartum weight retention, Rong et al. found that women with excessive gestational weight gain had significantly higher postpartum weight retention than women with adequate gestational weight gain (125). Postpartum weight retention in women with excess gestational weight gain exhibited a U-shaped trend; showing a decline during the early postpartum span (1 year) and then an increase in the following 3-15 years (125). These findings suggest that gestational weight gain, rather than pre-pregnancy BMI influences both the short- and long-term postpartum weight retention (125).

Endres et al. evaluated postpartum weight retention risk factors and relationship to obesity at one year in 744 postpartum women (126). Women had a mean pre-pregnancy BMI of 28 kg/m^2 and gained an average of 14.5 kg (32 pounds) during pregnancy, and at 1-year postpartum the women's mean BMI increased to 29 kg/m^2 (126). Approximately 75% of women were heavier than they were before becoming pregnant, including 47% who retained more than 4.5 kg (10 pounds) and 24% retaining more than 9 kg (20 pounds) (126). Of the 40% of women who had a normal pre-pregnancy BMI, one third were overweight or obese one-year postpartum (126). These findings indicate that postpartum weight retention is a significant contributor to the risk for obesity 1 year postpartum, including for women of normal pre-pregnancy weight (126).

There was no difference in weight at three-months postpartum, as a percent of pre-pregnancy weight between normal weight and overweight/obese participants. But there was a significant difference in weight retention at three-months postpartum between participants who met the IOM recommendations for weight gain and those participants who exceeded the weight gain recommendations. Women who gained excess weight during pregnancy retained 7% more weight than those women who met the recommendations for weight gain. This is consistent with other studies and reiterates the importance of gaining appropriate weight during pregnancy.

At three-months postpartum, we expected that more participants would meet the physical activity recommendations than during pregnancy. Interestingly, we found that women actually engaged in less MVPA after pregnancy than during pregnancy and that fewer participants met the recommendations for physical activity.

Strengths of Study Design

The use of accelerometers in the pregnant population is important to objectively measure physical activity. Using accelerometers to measure physical activity is not novel in children or adult populations but limited data has been collected using accelerometers in pregnant women. In most populations there is a tendency to overestimate duration and intensity of physical activity when using self-report measures. The data on physical activity was objectively measured in the study reported here, reducing the reporting bias and increasing the accuracy of results.

We were able to analyze a cohort of women and their engagement in physical activity at multiple time points during pregnancy to determine patterns and intensity of physical activity. A number of studies rely on cross-sectional data (i.e. NHANES data) to compare physical activity at different time points during pregnancy, which may not be as valuable as longitudinal studies where individual trends can be compared over time. Previous accelerometer studies in pregnant women indicate a need for additional longitudinal studies using objectively measured physical activity (101, 108).

Moreover, this study also collected data during the postpartum period enhancing the cohesiveness of our analysis to provide a broader picture of physical activity in pregnant women. Generally studies look at either physical activity during pregnancy or physical activity during the postpartum period. Gathering data at four time points both during pregnancy and at the postpartum period allows us to make reliable comparisons between physical activity, weight gain, and weight retention post-partum.

The PEN feasibility study was designed as an intervention for pregnant women to improve maternal and infant outcomes and incorporated several physical activity components to encourage activity during pregnancy. For the purposes of this analysis we did not compare control and intervention groups. Although we cannot draw conclusions about physical activity outcomes between control and intervention groups, the longitudinal, interventional study design is a strength of this project. Previous studies describing activity and duration of physical activity, using both objective and subjective measures, conclude that more intense intervention studies are imperative for this population to improve health outcomes (102, 104, 106, 122, 123).

Limitations of Study Design

This was a feasibility study, as such, and was not powered to demonstrate statistically significant differences between the control and intervention groups, normal weight vs. overweight/obese groups, or those meeting or exceeding the gestational weight gain recommendations. With a small sample size, outliers have a large effect on means, standard deviations and the statistical power, which reduced the chances of observing a true effect when one actually exists, defined as a type II statistical error. The sample in this study was mainly white women, who ere employed and of higher educational and socioeconomic status, and who were over the age of 30. This demographic profile limits the generalizability of our result to many other populations of women.

Another limitation of this study was the use of self-reported pre-pregnancy weight in all participants and the use of self-reported latest weight before delivery for 3 participants. Although self-report is the most common means of assessing pre-pregnancy weight, it may not be the most accurate. Since many women do not plan their pregnancies, and do not visit their primary care provider immediately before conception, pre-pregnancy body weight is not consistently measured and recorded by a medical provider. Furthermore, it is not practical to recruit women who are expecting to become pregnant in order to obtain a pre-pregnancy weight before starting a pregnancy-based intervention. For these reasons, self-reported pre-pregnancy weight is commonly used in research to determine pre-pregnancy BMI and to calculate gestational weight gain. A study by Shin et al. evaluated the validity of pre-pregnancy BMI weight status from self-reported pre-pregnancy height and weight in comparison to BMI from measured data during the first trimester of pregnancy among women participating in the NHANES (2003-2006) (127). Self-reported pre-pregnancy weight of 504 women was compared to imputed data, a method using multiple imputed values to infer the "true" value. The mean difference between self-reported verses imputed pre-pregnancy weight was -1.7 ± 0.1 kg and the measures were significantly correlated ($r = 0.98$; $p < 0.001$) which suggests agreement between the measures (127).

Distinguishing sedentary behavior from non-wear time is one of the challenges when using an accelerometer to measure physical activity. Most studies using accelerometers employ automated algorithms to identify non-wear time based on "zero counts" and allowances for "interruptions". Overestimation of non-wear-time occurs when participants wear the accelerometer but are very sedentary, resulting in erroneous exclusion or invalid days (128). One solution to this is to incorporate an activity log, in which participants are asked to record the times the accelerometer is put on and taken off. Women in the PEN study were not instructed to provide an activity log while wearing the accelerometer. This would have been helpful to compare the type of activity reported and intensity level output provided by the accelerometer. Additionally some women wore the device for an extended period of time (up to 23 hours/day). Without a corresponding activity log it was difficult to determine which hours should be included in the analysis. Although in a study comparing methods to determine wear-time, Peeters et al. found that automated filters are as accurate as a combination of automated filters and activity logs for differentiating between accelerometer non-wear-time and sedentary time (128).

In this evaluation nutritional intake was not taken into account, energy intake likely impacted weight gain during pregnancy and weight retention postpartum. Weight gain is a function of energy expenditure through physical activity and metabolism, as well as energy intake from food and drink consumption. As a result, amount and level of physical activity only reflect half of the equation. Physical activity may affect appetite and food intake during pregnancy; furthermore, women who are health-oriented may be more physically active and eat more healthfully. Future studies are needed in which both sides of the energy balance equation are taken into account in relation to gestational weight gain and weight retention postpartum. Additionally we did not adjust postpartum weight loss based on breastfeeding initiation, duration, or exclusivity. In this study all women initiated breastfeeding and most continued to breastfeed at least to some extent at three-months postpartum, for these reasons we did not feel it was necessary to consider this as a variable. In future studies this may be an important consideration to make.

Conclusions

The first aim of our study was to describe the patterns of daily physical activity during pregnancy and at three-months postpartum. Our study sample showed that the amount of MVPA performed decreased throughout pregnancy and was even lower at three-months postpartum. Fewer than 50% of participants met the physical activity recommendation of 30 minutes or more of MVPA on 4 or more days of the week at any time point during pregnancy.

The second aim of our study was to determine if normal weight women would perform more MVPA than overweight/obese women during each trimester of pregnancy and overall and if normal weight women would meet the physical activity recommendation more frequently than overweight/obese women. Women who were normal weight before becoming pregnant performed more MVPA early in pregnancy and at three-months postpartum than those who were overweight/obese before becoming pregnant. Overall in pregnancy normal weight women performed more MVPA than overweight/obese women. Therefore we accept our hypothesis in part; we confirmed that the amount of time spent in MVPA was higher among normal weight than overweight/obese women during the first trimester and overall during pregnancy and at three-months postpartum, but we reject this hypothesis during the second and third trimesters of pregnancy when there were no differences between groups.

The third aim of this study was to determine if women who meet the physical activity recommendation during each trimester of pregnancy would be more likely to meet the IOM gestational weight gain recommendation and would retain less weight at three-months postpartum. We found that meeting the physical activity recommendations at any trimester of pregnancy did not significantly impact the odds of meeting the recommendation for gestational weight gain. Therefore we reject the hypothesis that women who meet the physical activity recommendation of 30 minutes of MVPA per day at least four days per week during the first, second, and third trimesters of pregnancy would be more likely to meet the IOM recommendation for weight gain during pregnancy than those who did not meet the physical activity recommendation.

We also evaluated if women who met the physical activity recommendation overall in pregnancy would be more likely to meet the gestational weight gain recommendations and would retain less of the weight they gained during pregnancy at three-months postpartum. This hypothesis could not be tested overall using the physical activity recommendation of 30 minutes or more of MVPA on 4 or more days per week because only two participants met this criterion. However, using the recommendation of 150 minutes of MVPA per week, we accept out hypothesis that at three-months postpartum mean maternal weight was lower among women who met the physical activity recommendation compared to those who did not. Finally, at three-months postpartum, mean maternal weight was not lower among women who met the physical activity recommendation of 30 minutes or more of MVPA on 4 or more days of the week so this hypothesis was rejected

These findings reinforce the importance of identifying ways to support all women, but especially overweight/obese women to make healthy lifestyle choices. Previous qualitative work in the United Kingdom found that obese pregnant women feel they do not receive adequate advice and support from health care providers around appropriate physical activity during pregnancy and would welcome more guidance (129). Similar findings have been reported in the United States (130).

Future Directions and Practical Implications

Preliminary evidence, based on observational studies, suggest that exercise during pregnancy may be associated with many benefits, including reduced risk of preeclampsia, gestational diabetes, depressed mood, low back pain, and complications during delivery. There is insufficient evidence to conclude that there are benefits of physical activity on newborn outcomes, however there is also little evidence that physical activity during pregnancy is harmful to the fetus or mother. A 2012 Cochrane review indicates a lack of evidence that physical activity during pregnancy is harmful (1, 33). The recommendations published in 2002 by the ACOG, and other observational studies suggests there are positive effects of physical activity during pregnancy, and that practitioners should encourage their patients to exercise during healthy pregnancies (1, 33).

To better understand the relationship between physical activity and pregnancy-related outcomes, there need to be larger, well-powered, methodologically-sound, randomized controlled trials examining the effect of physical activity during pregnancy on maternal and newborn outcomes. Given the importance of healthy birth outcomes and the high financial and human cost regarding birth-related complications, research in the area of physical activity during pregnancy should be a priority. Practitioners including dietitians should be aware of contraindications to increasing physical activity and be able to counsel women on how to initiate and maintain appropriate physical activity programs during and after pregnancy.

For many women, pregnancy is a time to make health changes that improve both their own health and that of their developing infant. Given the relationships between MVPA and gestational weight gain and return to pre-pregnancy weight, all women with uncomplicated pregnancies, especially those who are overweight or obese before pregnancy, and/or those who gain more gestational weight than is recommended, should be encouraged to be physically active before, during, and after pregnancy.

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APPENDIX A

MVPA Minutes Per Week

Table 14. Minutes of MVPA per week based on pre-pregnancy weight status during the first, second, and third trimester and at three-months postpartum*

	Normal Weight (n=14)	Overweight/obese (n=13)
First Trimester†	278 ± 141 (89 – 578)	169 ± 96‡ (41 – 379)
Second Trimester	207 ± 127 (12 – 432)	145 ± 84 (24 – 291)
Third Trimester	178 ± 141 (15 – 477)	117 ± 92 (29 – 338)
Overall	222 ± 140 (12 – 578)	143 ± 87‡ (24 – 379)
Postpartum	153 ± 104 (20 – 318)	88 ± 49 (22 – 170)

* Mean ± SD, (range)

† MVPA minutes per week

‡ Significantly different from normal weight women (p-value <0.05)

APPENDIX B

Swartz Cut-Points

Table 15, 16, and 17 and Figure 12 show data analyzed by Swartz cut-points, unadjusted for accelerometer wear-time. Swartz cut-points provided a much different output for minutes in each intensity category than Troiano cut-points. Without adjusting for wear-time, using Swartz cut-points showed that all participants in the first, second, and third trimesters spent 30.6 (± 6.1%), 20 (± 5.9%) and 27.9 (± 6.2%) in MVPA, respectively. This accounted for more than 200 minutes (3.3 hours) with a range from 199 – 348 minutes/day of MVPA at all time points.

Table 15. Maternal physical activity during each trimester of pregnancy and at three-months postpartum, unadjusted for accelerometer wear-time using Swartz cut-points*

	1st Trimester (Baseline) (n=26)	2nd Trimester (n=26)	3rd Trimester (n=25)	Postpartum (n=25)
Wear-time (minutes)	752 ± 95.7 (541 – 961)	771 ± 93.2 (589 – 1123)	780 ± 118.1 (608 – 1236)	739 ± 96.5 (599 – 937)
Counts per minute (cpm)	614 ± 142.6 (296 – 930)	557 ± 112.1 (368 – 768)	529 ± 153.0 (328 – 871)	568 ± 149.1 (335 – 893)
Metabolic Equivalents of Task (METs)	1.20 ± 0.12 (1.03 – 1.53)	1.17 ± 0.10 (1.03 – 1.38)	1.16 ± 0.10 (1.04 – 1.39)	1.13 ± 0.09 (1.03 – 1.34)
Physical Activity (Swartz cut-points)				
Light (minutes/day)	523 ± 68.5 (381 – 1074)	540 ± 88.0 (428 – 874)	563 ± 11.1 (436 – 972)	503 ± 81.8 (357 – 727)
Moderate (minutes/day)	221 ± 60.1 (119 – 348)	224 ± 49.5 (129 – 314)	211 ± 53.0 (116 – 344)	230 ± 54.2 (141 – 341)
Vigorous (minutes/day)	11 ± 11.8 (0 – 50)	6 ± 9.2 (0 – 33)	5 ± 9.8 (0 – 33)	6 ± 7.0 (0 – 19)
MVPA (minutes/day)	232 ± 59.1 (119 – 349)	230 ± 49.9 (156 – 318)	216 ± 52.0 (141 – 347)	236 ± 56.3 (141 – 353)
% MVPA	30.6% ± 6.1	20.0% ± 5.9	27.9% ± 6.2	31.9% ± 6.2

* Mean ± SD (range), percent of total

† MVPA: Moderate to vigorous physical activity

Table 16. Maternal physical activity during each trimester of pregnancy and at three-months postpartum for normal weight and overweight/obese women, unadjusted for accelerometer wear-time*

	1st Trimester (Baseline)		2nd Trimester		3rd Trimester		Postpartum	
	Normal Weight (n= 14)	**Overweight/ Obese (n=12)**	**Normal Weight (n=13)**	**Overweight/ Obese (n=13)**	**Normal Weight (n=13)**	**Overweight/ Obese (n=12)**	**Normal Weight (n=14)**	**Overweight/ Obese (n=11)**
Wear-time (minutes)	734 ± 79.1 (564 – 845)	773 ± 111.9 (541 – 961)	761 ± 53.1 (675 – 838)	781 ± 122.7 (589 – 1123)	744 ± 83.8 (608 – 843)	819 ± 139.7 (710 – 1236)	715 ± 90.5 (599 – 937)	770 ± 99.1 (619 – 900)
Counts per minute (cpm)	634 ± 162.1 (358 – 930)	591 ± 118.5 (290 – 720)	567 ± 130.0 (368 – 768)	546 ± 95.2 (436 – 746)	555 ± 172.2 (346 – 871)	501 ± 126.1 (328 – 734)	599 ± 173.7 (335 – 893)	529 ± 105.8 (368 – 666)
Metabolic Equivalents of Task (METs)	1.23 ± 0.13 (1.53 – 1.20)	1.17 ± 0.09 (1.03 – 1.33)	1.18 ± 0.11 (1.03 – 1.38)	1.15 ± 0.1 (1.05 – 1.31)	1.18 ± 0.12 (1.04 – 1.39)	1.14 ± 0.08 (1.04 – 1.28)	1.16 ± 0.10 (1.03 – 1.34)	1.11 ± 0.05 (1.03 – 1.21)
Physical Activity (Swartz cut points)								
Light (minutes/day)	516 ± 67.6 (381 – 617)	531 ± 71.6 (401 – 671)	533 ± 66.0 (428 – 623)	549 ± 107.6 (433 – 874)	538 ± 78.8 (436 – 651)	591 ± 136.3 (479 – 972)	483 ± 83.7 (357 – 727)	529 ± 75.2 (452 – 680)
Moderate (minutes/day)	208 ± 41.6 (155 – 286)	236 ± 75.7 (119 – 348)	220 ± 56.6 (129 – 307)	228 ± 43.1 (154 – 314)	197 ± 48.1 (116 – 288)	227 ± 55.8 (142 – 344)	224 ± 53.0 (141 – 341)	237 ± 57.3 (162 – 336)
Vigorous (minutes/day)	15 ± 5.9 (1 – 50)	6 ± 6.4 (0 – 19)	10 ± 3.3 (0 – 33)	11 ± 5.1 (0 -19)	8 ± 12.8 (0 – 33)	2 ± 1.9 (0 – 5)	8 ± 7.5 (0 – 19)	4 ± 5.7 (0 -18)
MVPA (minutes/day)	224 ± 40.8 (170 – 288)	242 ± 76.0 (119 – 349)	230 ± 56.8 (157 – 312)	231 ± 44.3 (156 – 318)	205 ± 46.6 (148 – 296)	228 ± 57.0 (141 – 347)	232 ± 55.7 (141 – 353)	241 ± 59.4 (162 – 338)
% MVPA	30.6% ± 4.9	30.8% ± 7.3	30.2% ± 7.1	29.8% ± 4.8	27.7% ± 5.6	28.2% ± 7.0	32.5% ± 6.8	31.1% ± 5.6

* Mean ± SD (range), percent of total

† MVPA: Moderate to vigorous physical activity

Table 17. Mean minutes of MVPA determined using Swartz cut-points unadjusted for accelerometer wear-time during the first, second, and third trimesters of pregnancy, and at three-months postpartum

	1st Trimester (Baseline) (minutes/day)	2nd Trimester (minutes/day)	3rd Trimester (minutes/day)	Postpartum (minutes/day)
Unadjusted Swartz				
Normal Weight	224 (204.2 – 245.5)	226.8 (210.4 – 257.5)	210 (201.8 – 257.3)	235 (208.7 – 264.8)
Overweight/ Obese	244 (206.9 – 288.0)	232.7 (210.4 – 257.5)	278 (201.8 – 257.3)	241 (206.6 – 281.5)

*Mean (95% CI)

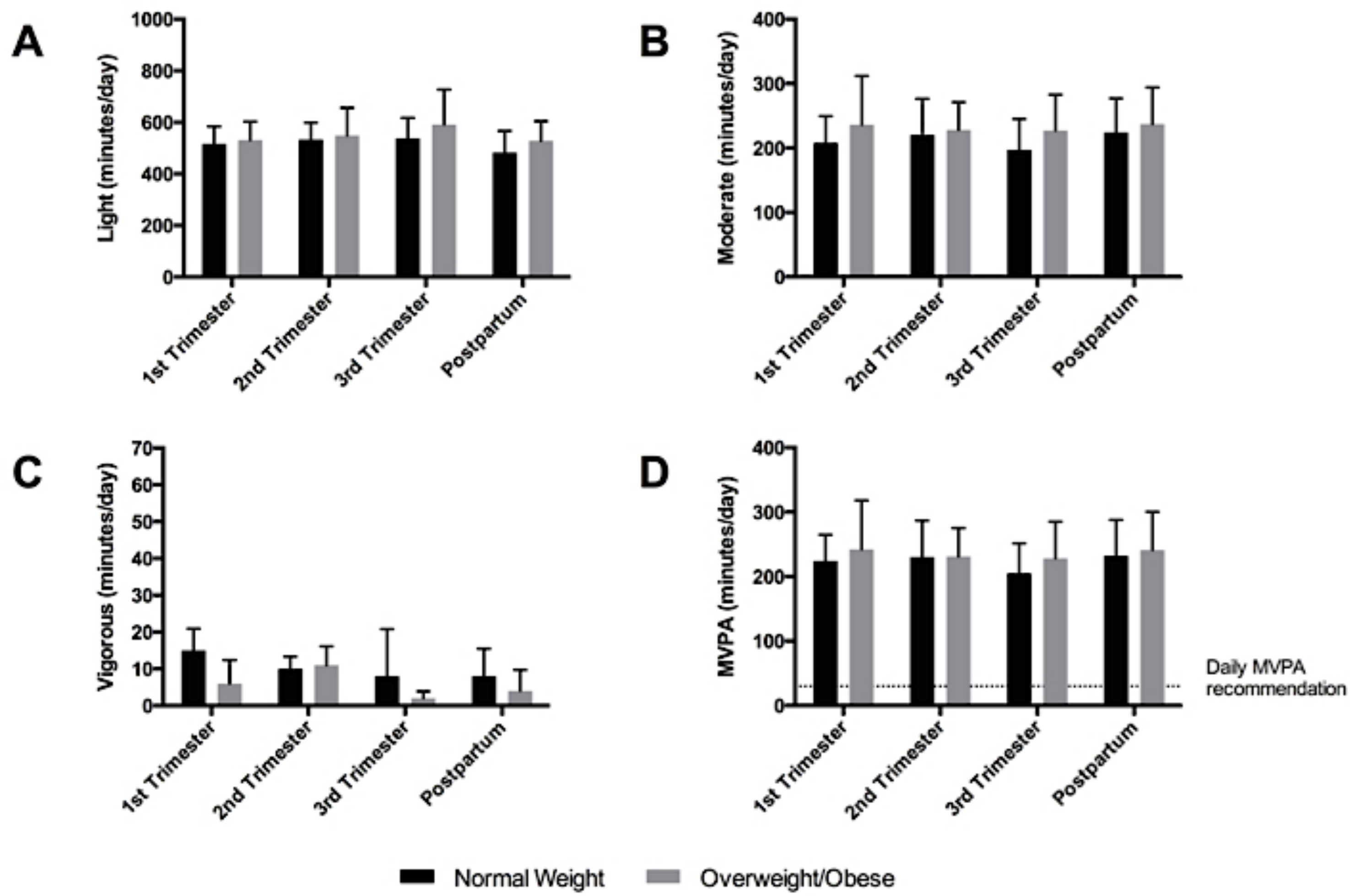

Figure 13. Minutes of light, moderate, vigorous and total MVPA during each trimester of pregnancy and at three-months postpartum using Swartz cut-points

APPENDIX C

Adjustment for 720 Minutes of Accelerometer Wear-Time

To ensure comprehensiveness of analyses wear-time was adjusted using a model, to determine minutes of MVPA that occurred in a 720 minute time period (12 hours). Mean time spent in MVPA (minutes) was estimated using negative binomial regression. Activity data from each trimester and within each intensity cut-point range was analyzed separately. For each trimester and each cut-point, several models were fit: one that did not include wear-time and one that included log(wear-time) as an offset. This later model estimated the mean number of minutes spent in MVPA per minute of wear-time. These models were used to estimate overall mean time spent in MVPA (minutes) as well as separate means according to pre-pregnancy BMI (overweight/obese verses normal weight). The standard error of each model generated was to account for adjusted clustering of data due to multiple collection days per subject, per trimester. In models that accounted for wear-time, the reported mean MVPA was scaled to reflect 720 minutes (12 hours) of wear-time. Summary data generated from adjusted wear-time measures are represented in Tables 18, 19, and 20.

Table 18 presents summary data for physical activity for all women at each trimester of pregnancy and at three-months postpartum, adjusted to 720 minutes of wear-time. Wear-time, cpm, and METs remain unchanged regardless of employing cut-point decisions. The impact of adjustment using Troiano cut-points provided a difference of 1-3 minutes spent in MVPA or a 0.2% difference in percent of wear-time time spent in MVPA. The impact of adjustment using Swartz cut-points had higher variability and provided as much as a 15 minutes difference in MVPA and 8% difference in percent wear-time spent in MVPA.

Table 18. Maternal physical activity during each trimester of pregnancy and at three-months postpartum, adjusted for accelerometer wear-time (720 minutes)*

	1st Trimester (Baseline) (n=26)	2nd Trimester (n=26)	3rd Trimester (n=25)	Postpartum (n=25)
Wear-time (minutes)	720	720	720	720
Counts per minute (cpm)	614 ± 142.6 (296 – 930)	557 ± 112.1 (368 – 768)	529 ± 153.0 (328 – 871)	568 ± 149.1 (335 – 893)
Metabolic Equivalents of Task (METs)	1.20 ± 0.12 (1.03 – 1.53)	1.17 ± 0.10 (1.03 – 1.38)	1.16 ± 0.10 (1.04 – 1.39)	1.13 ± 0.09 (1.03 – 1.34)
Physical activity (Troiano cut-points)				
Light (minutes/day)	687 ± 18.4	695 ± 15.1	697 ± 16.8	706 ± 17.2
Moderate (minutes/day)	31 ± 16.7	29 ± 15.6	22 ± 16.2	25 ± 15.5
Vigorous (minutes/day)	2.0 ± 4.0	0.7 ± 4.3	0.7 ± 2.3	2.0 ± 2.6
MVPA† (minutes/day)	33 ± 18.4	30 ± 20.8	27 ± 19.6	21 ± 15.1
% MVPA	4.6%	4.2%	3.8%	2.9%
Physical Activity (Swartz cut-points)				
Light (minutes/day)	500 ± 44.0	504 ± 42.7	519 ± 44.5	490 ± 44.6
Moderate (minutes/day)	209 ± 45.6	210 ± 43.1	196 ± 44.8	224 ± 41.8
Vigorous (minutes/day)	10 ± 11.4	6 ± 8.5	5 ± 9.7	6 ± 7.2
MVPA (minutes/day)	220 ± 44.0	216 ± 42.7	201 ± 44.5	230 ± 44.6
% MVPA	29.3%	28.0%	25.8%	31.1%

* Mean ± SD (range), percent of total
† MVPA: Moderate to vigorous physical activity

Table 19. Maternal physical activity during each trimester of pregnancy and at three-months postpartum for normal weight and overweight/obese women, adjusted for accelerometer wear-time (720 minutes)*

	1st Trimester (Baseline)		2nd Trimester		3rd Trimester		Postpartum	
	Normal Weight (n= 14)	Overweight/ Obese (n=12)	Normal Weight (n=13)	Overweight/ Obese (n=13)	Normal Weight (n=13)	Overweight/ Obese (n=12)	Normal Weight (n=14)	Overweight/ Obese (n=11)
Wear-time (minutes)	720	720	720	720	720	720	720	720
Counts per minutes (cpm)	634 ± 162.1 (358 – 930)	591 ± 118.5 (290 – 720)	567 ± 130.0 (368 – 768)	546 ± 95.2 (436 – 746)	555 ± 172.2 (346 – 871)	501 ± 126.1 (328 – 734)	599 ± 173.7 (335 – 893)	529 ± 105.8 (368 – 666)
Metabolic Equivalents of Task (METs)	1.23 ± 0.13 (1.53 – 1.20)	1.17 ± 0.09 (1.03 – 1.33)	1.18 ± 0.11 (1.03 – 1.38)	1.15 ± 0.1 (1.05 – 1.31)	1.18 ± 0.12 (1.04 – 1.39)	1.14 ± 0.08 (1.04 – 1.28)	1.16 ± 0.10 (1.03 – 1.34)	1.11 ± 0.05 (1.03 – 1.21)
Physical activity (Troiano cut-points)								
Light (minutes/day)	679 ± 19.0	696 ± 13.0	690 ± 16.3	759 ± 119.7	693 ± 16.9	702 ± 12.2	706 ± 17.2	706 ± 7.2
Moderate (minutes/day)	37.4 ± 17.1	24 ± 13.3	29 ± 15.6	21 ± 12.9	26 ± 18.7	18 ± 12.1	25 ± 15.5	13 ± 6.4
Vigorous (minutes/day)	4 ± 5.1	0.3 ± 0.7	1 ± 4.3	0 ± 0.1	1.2 ± 3.2	0 ± 0.3	2 ± 2.6	1 ± 2.7
MVPA† (minutes/day	41 ± 19.0	24 ± 13.3	30 ± 20.8	17 ± 12.9	27 ± 19.6	18 ± 12.2	27 ± 17.2	14 ± 2.7
% MVPA	5.7%	3.3%	4.2%	2.4%	3.8%	2.5%	3.8%	1.9%
Physical Activity (Swartz cut-points)								
Light (minutes/day)	502 ± 36.8	498 ± 52.8	503 ± 51.0	506 ± 34.5	521 ± 40.1	517 ± 50.5	486 ± 48.6	496 ± 40.6
Moderate (minutes/day)	203 ± 38.4	217 ± 53.7	208 ± 51.2	212 ± 35.3	191 ± 41.0	202 ± 49.9	225 ± 44.8	221 ± 39.7
Vigorous (minutes/day)	14 ± 13.4	5 ± 5.4	9 ± 10.7	3 ± 3.3	8 ± 12.7	1 ± 1.5	8.3 ± 8.1	3 ± 4.8
MVPA (minutes/day)	218 ± 36.8	222 ± 52.8	217 ± 42.3	214 ± 34.5	199 ± 40.1	203 ± 50.5	234 ± 48.6	224 ± 40.6
% MVPA	30.3%	30.8%	30.1%	29.7%	27.6%	28.2%	32.5%	31.1%

* Mean or percent ± SD (range)

† MVPA: Moderate to vigorous physical activity

Table 20. Mean minutes of MVPA determined using Troiano and Swartz cut-points adjusted to 720 minutes of accelerometer wear-time during the first, second, and third trimesters of pregnancy, and at three-months postpartum

	1st Trimester (Baseline) (minutes/day)	2nd Trimester (minutes/day)	3rd Trimester (minutes/day)	Postpartum (minutes/day)
Adjusted Troiano				
Normal Weight	43 (32.4 – 54.3)	32 (23.3 – 40.4)	29 (18.0 – 40.4)	28 (18.1 – 37.0)
Overweight/ Obese	25 (17.1 – 32.5) †	21 (14.0 – 27.3) †	17 (10.3 – 24.2)	13 (9.2 – 17.5) †
Adjusted Swartz				
Normal Weight	221 (202.2 – 239.6)	213 (187.2 – 239.9)	203 (181.9 – 225.0)	236 (209.9 – 262.5)
Overweight/ Obese	227 (197.6 – 256.1)	217 (197.5 – 237.1)	203 (177.9 – 227.6)	227 (202.2 – 251.5)

*Mean (95% CI)

† Significantly lower than normal weight group, p-value <0.05

APPENDIX D

Accelerometer Evidence Table

Author, Title	Date of Publication	Subjects, number of measures	Cut points	Wear-time	Results	Conclusions
Bell, Measuring physical activity in pregnancy: a comparison of accelerometry and self-completion questionnaires in overweight and obese women	2013 (101)	59 overweight/ obese pregnant women, one time point (median 12.5 weeks gestation	Freedson (5-second epochs)	3 or more days, >500 minutes (asked to wear for 7 days)	35 minutes in MVPA (median duration + IQR)	Objective measure should be used where possible in studies investigating physical activity and pregnancy outcome
Evenson, Changes in physical activity among postpartum overweight and obese women: results from the KAN-DO study	2013(102)	132 overweight/ obese women, baseline = 24 weeks postpartum, and follow-up= 10 months later	Colley (2011) cut points? Moderate 1525 – 3961, vigorous > 3962	Wear-time 13.3 hours/day at baseline, 12.7 hours/day follow-up, median number of days was 7 at both time periods	MVPA median at baseline = 6.9 min/day and follow-up 8.8 min/day	Small increase in PA as postpartum time progresses. Women fell short of recommendation of 150 minutes/week. More intensive interventions are needed to help overweight and obese women integrate physical activity and reduce sedentary behavior after the birth of a baby.
Evenson, Self-reported and objectively measures physical activity among a cohort of postpartum women: the PIN postpartum study	2012 (103)	181 women (3-month measure), 204 women (12-month measure), two time points	Freedson, Swartz, and summary cut points from NHANES data by Troiano (calculated originally by taking the weighted average of cut points from Freedson, Yngve, Leenders, & Brage (60-second epochs)	Average wear time at 3 months was 12.2 hours/day, average wear time at 12 months was 12.8 hour/day(asked to wear for 7 days)	3-month average cpm = 364 12-moth average cpm = 394 At both time periods vigorous activity was 1-3 minutes/day and moderate 16 minutes/day Regardless of cut points vigorous = 1-3 minutes (<1%) Swartz = 276-287 minutes moderate Troiano/Freedson = 17-21 minutes moderate	Interventions are needed to help women integrate more moderate to vigorous physical activity and to capitalize on improvements in sedentary behavior during postpartum *Findings using either Freedson or Troiano cut-points were similar

Gingras, Accelerometery-measured physical activity and inflammation after gestational diabetes	2013 (116)	94 women who had GDM between 2003 and 2013 tested 2.9 ± 2.2 years after delivery	Freedson (60-second epochs)	4 or more days, for 10 or more hours wear time/day	Only 31% of women accumulated 150 minutes MVPA per week Mean moderate = 18, mean vigorous = 1	Most women with prior GDM did not meet the recommended practice of MVPA, measured with accelerometers, in the years after delivery
Hayes, Change in level of physical activity during pregnancy in obese women: findings from the UPBEAT pilot trial	2015 (105)	183 obese pregnant women at 16-18 weeks, 27-28 weeks, and 35-36 weeks gestation	Freedson cut points, Total activity as a proportion of accelerometer wear time	Three or more days with 500 or more minutes/day	Absolute values (minutes/day) 1st Trimester Light = 174.8 MPVA= 39.0 (4.8%) Cpm = 299 2nd trimester Light = 158.8 MPVA= 34.5 (4.3%) Cpm = 278 3rd trimester Light = 169.7 MPVA= 23.3 (3.0%) Cpm = 248	Physical activity in early pregnancy was the factor most strongly associated with physical activity at later gestation. Women should be encouraged to participate in physical activity before becoming pregnant and maintain their activity levels during. MVPA decreased with gestation
Hawkins, Physical activity, sedentary behavior, and C-reactive protein in pregnancy	2014 (106)	294 NHANES, cross sectional with different participants at each trimester of pregnancy	Freedson cut points (60-second epochs). Each minute of MVPA was summed and divided by the number of valid days of wear time to obtain daily averages.	Four or more days with 10 or more hours of wear time	Median (IQR) 1st trimester, Light = 229.6 (14.2), MVPA = 71 (51.4 – 314.3), Cpm = 218.7 (173.2 – 314.3) 2nd Trimester, Light = 235.3 (5.2), MVPA = 77.7 (56.6 – 93.8), Cpm = 231.9 (177.8 – 271.7) 3rd Trimester, Light = 217.4 (12.1), MVPA = 69 (46.4 – 92.3), Cmp = 200.9 (161 – 254.3)	This population-based sample of pregnant women found that light physical activity during the second trimester of pregnancy was associated with lower c-reactive protein levels. These findings highlight the need for intervention studies designed to promote active lifestyles among pregnant women.

Ruifrok, The relationship of objectively measured physical activity and sedentary behavior with gestational weight gain and birth weight	2014 (107)	Secondary analysis – Randomized controlled trial of 111 women measured around 15 and 32-35 weeks gestation.	Troiano cut points Time spent by the participants was measured as a percentage of total registration time.	At least 8 hours of wear time.	Early pregnancy = 32% of women spent greater than or equal to 30 minutes/day in MVPA (35% of wear time) Late Pregnancy = 12% MVPA baseline (15 weeks) = 24 (SD 16) minutes/day MVPA late (32 weeks) = 18 (SD 22) minutes/day	53% of all women gain more weight then advised by the IOM. This is even more pronounced in women with overweight or obesity, with 68.9% and 59.8% respectively. No significant associations between time spent in MVPA or sedentary behavior with gestational weight gain or birth weight
Van Poppel, Longitudinal relationship of physical activity with insulin sensitivity in overweight and obese pregnant women	2013 (108)	Longitudinal study with measurements at 15, 24, and 32 weeks of gestation. 24 women	Freedson cut points, total minutes spent during each period of intensity were summed and then divided by the total number of days worn	60-second epochs, 4 consecutive days, at least 8 hours of wear time	MVPA min/wk 15 weeks = 212 (114) 24 weeks = 183 (139) 32 weeks = 159 (103)	In overweight/obese pregnant women, MVPA was associated with improved insulin sensitivity, insulin response, and decreased triglycerides at 32 weeks of pregnancy. Supports efforts for counseling obese women at risk for GDM