Blossom Project 2: Longitudinal assessment of physical activity, sedentary behavior, diet quality, and weight gain during pregnancy

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Blossom Project 2: Longitudinal assessment of physical activity, sedentary behavior, diet quality, and weight gain during pregnancy

by

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A thesis submitted to the graduate faculty in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

Major: Nutritional Sciences

Program of Study Committee:
Christina Campbell, Major Professor
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Gregory Welk

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DEDICATION

To my father, the late Dr. D, whose thirst for knowledge and passion for creative thought never ceases to provide me with inspiration; to my mother, Betsy, whose constant encouragement, faith in my abilities, and knowledge of medical care supports my journey in life; to my sister, Danielle, for her understanding, wisdom, and advice; to my fiancé, Kyle, for his love, support, and sacrifice for the pursuit of my dreams; and lastly, to my major professor, Dr. Christina Campbell, whose unfailing confidence in my ability to balance life and school provided a crucial foundation for my achievements.
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Conclusion

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I would like to thank my committee chair, Christina Campbell, for her constant encouragement, dedication to my success, and profound mentorship. I would also like to thank my committee members, Philip Dixon, Anna Peterson, and Gregory Welk, for their guidance, support, and advice throughout the course of this research.

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ABSTRACT

The benefits of physical activity (PA) during pregnancy have been well documented, but little is known about the contribution of activity sub-components including sleep, sedentary, light, moderate, and vigorous activity on gestational weight gain (GWG). Additionally, the relationship between diet quality and GWG has yet to be determined.

A prospective, longitudinal study was conducted during 2\textsuperscript{nd} and 3\textsuperscript{rd} trimester to objectively quantify and identify modifiable aspects of total PA including sleep, sedentary, light, moderate, and vigorous activity, and dietary intake. Participants (n=46) wore a SenseWear\textsuperscript{®} Armband and an activPAL\textsuperscript{TM} activity monitor for seven consecutive days during which a weighed 3-day diet record was also completed. Paired t-tests were used to compare data across pregnancy and multiple regression was used to identify predictors of GWG.

Time spent in nighttime sleep, naps, sedentary behavior (SB), and moderate PA did not change across pregnancy while light and vigorous PA significantly decreased. During both the 2\textsuperscript{nd} and 3\textsuperscript{rd} trimester women spent an average of 75\% of time awake in sedentary behavior even though 65\% (week 18) and 61\% (week 35) met the prenatal PA recommendations. Additionally, prediction equations showed positive correlations between protein intake (P = 0.071) and MET-minutes (P = 0.038) with GWG at week 18 (R\textsuperscript{2} = 0.29, rMSEP = 2.18); and between carbohydrate intake (P = 0.098) and MET-minutes (P = 0.038) with GWG at week 35 (R\textsuperscript{2} = 0.19, rMSEP = 3.99). Due to the large portion of the day spent in SB regardless of whether or not prenatal PA recommendations were met, and the observed relationship between total activity (MET-minutes) and weight gain across pregnancy, an
overall increase in activity during pregnancy should be promoted. Furthermore, dietary quality of CHO should be investigated with respect to GWG.
CHAPTER 1. INTRODUCTION

Introduction

Excessive gestational weight gain (GWG), or weight gain greater than recommended by the Institute of Medicine (IOM), has been identified as an independent and modifiable risk factor for maternal and fetal health. Excessive GWG has been associated with immediate risks during pregnancy such as (GDM) (1), preeclampsia (2-5), and large for gestational age infants (2,6) in addition to posing an increased future health risk of obesity (7) and chronic disease (8) in both the mother and child.

Identified significant predictors of GWG include pre-pregnancy BMI (9-10), excessive energy intake (11), dietary components (12), lack of moderate physical activity (PA) (13-15), environmental factors (16-17), familial interactions (18), and cultural practices (19). Pre-pregnancy PA and dietary intake have largely been the focus of past observational and intervention studies aiming to identify contributors to GWG. However, sedentary behavior (SB) during pregnancy has not been thoroughly considered as a contributor to GWG and thus may warrant more attention. When developing strategies to prevent excessive GWG it may be important to consider all aspects of lifestyle including diet, PA, SB, and sleep.

Gestational weight gain is associated with infant birth weight and post-partum weight retention in women who consume in excess of their estimated energy needs (10). Maternal diet may also have an effect on the risk of preterm birth, specifically in terms of meal patterns with less frequent eating increasing risk of preterm birth independent of total energy intake (20-21). Both a high carbohydrate intake (> 340g/day) early in pregnancy and a low
intake of dairy and meat protein (≤ 76 g/day) late in pregnancy, have individually been associated with lower placental and birth weights (12). Low placental weight indicates suboptimal nutrition transferred to the fetus and can thereby result in impaired fetal growth. In order to achieve proper maternal and fetal growth, nutritional guidelines should be followed and diet should be composed of high quality, nutrient-dense foods.

Physical activity has also been identified as a contributor to GWG. Regular PA, defined as at least three days per week of moderate activity, has been shown to reduce the risk of GDM (22-23), pre-eclampsia (23-25), and pre-term birth (26-28). Additionally, PA has been documented as a potential strategy to reduce excessive GWG (13-15,29-30).

Physical activity recommendations during pregnancy advise participation in moderate PA most days of the week. However, little attention has been given to the activity that comprises the remainder of the day, which is as much as 23 hours and 30 minutes when referring to the AGOG recommendations of 30 minutes of activity per day. In non-pregnant adults, SB is associated with metabolic syndrome, cardiovascular risk, insulin resistance, and confers an increased risk of being overweight or obese. Evenson and Wen analyzed the prevalence of SB using 2003-2006 NHANES data for 359 pregnant women wearing an ActiGraph accelerometer and found the women spent 57.1% or 7 hours of their monitored time in SB (31). Considering that maternal weight status during pregnancy can influence the future health of the baby, it is imperative that the evaluation of the relationship between PA and pregnancy include the measurement of SB. This will allow for appropriate conclusions to be made between the relationship between prenatal PA and maternal/infant health outcomes.
Although interventions combining diet and exercise have been successful in reducing the prevalence of excessive GWG, there is still room for improvement. With the growing prevalence of inactivity, the concept of reducing SB separately from increasing moderate-vigorous PA is an important next step as it relates to the prevention of excessive GWG during pregnancy. In order to gain a complete perspective of the effects of lifestyle on GWG, aspects of diet quality and PA including SB patterns should be considered. Therefore, the purpose of this prospective, longitudinal study was to objectively quantify total habitual activity (sedentary, light, moderate, and vigorous) using multiple, consecutive 24-hour monitoring periods in addition to dietary intake to predict GWG in healthy women with a low-risk pregnancy.

**Thesis Organization**

This thesis includes a comprehensive introduction, review of literature, two manuscripts, and a conclusion. The first manuscript (Chapter 3), “Distribution of time spent in physical activity and sedentary behaviors during pregnancy: A longitudinal analysis with detailed objective monitoring” will be submitted to Medicine and Science in Sports and Exercise. The second manuscript (Chapter 4), “Carbohydrate intake and total daily intake and total daily physical activity predict gestational weight gain in late pregnancy”, will be submitted to the American Journal of Clinical Nutrition. The appendices of this thesis contain relevant statistical analyses and graphics, as well as documents utilized for study enrollment and data collection.
CHAPTER 2. LITERATURE REVIEW

Gestational Weight Gain

According to the Centers for Disease Control and Prevention (CDC), gestational weight gain (GWG) is “the amount of weight gained from conception to delivery” (32). Excessive GWG, or weight gain greater than recommended by the Institute of Medicine (IOM), has been identified as an independent and modifiable risk factor for maternal and fetal health. Excessive GWG has been associated with immediate risks during pregnancy such as (GDM) (1), preeclampsia (2-5), and large for gestational age infants (2,6) in addition to posing an increased future health risk of obesity (7) and chronic disease (8) in both the mother and child.

Pre-pregnancy body mass index (BMI) and GWG are recognized independent risk factors for future maternal and infant risk of obesity, cardiovascular disease, and diabetes (7-8). Maternal outcomes of excessive GWG can have long term consequences that may vary by pre-pregnancy BMI. Excessive GWG in women of all pre-pregnancy BMI classes has been related to increased rates of gestational hypertension and cesarean delivery (2). In addition, women who are obese prior to pregnancy also have an increased risk of preeclampsia and abnormal glucose tolerance (3-5). Women with a normal pre-pregnancy BMI and excessive GWG have an increased rate of labor augmentation (2). Nulliparous women who gained excessive weight between weeks 15 and 18 of gestation were shown to have increased rates of gestational diabetes mellitus (GDM) compared to their counter-parts who did not gain excessive weight (1). In addition to the prevalence of excessive GWG in the U.S., 71% of Canadian women have been shown to exceed weekly IOM weight gain
recommendations (9). In addition, those who exceeded total GWG recommendations were more likely to retain weight three months post-partum regardless of pre-pregnancy BMI (9).

Fetal outcomes of excessive GWG can have a long term effect on the growth and health of the child. In overweight and obese mothers, excessive GWG is related to an increased risk for macrosomic offspring (6), weight for age greater than the 90th percentile (6), and overweight/obese offspring in their adolescent and adult years (33). Offspring of women with a normal pre-pregnancy BMI but who gained excessive gestational weight had a significantly higher risk (odds ratio 4.0) of having an infant with a weight for age greater than the 90th percentile six months post birth (6). Women who gained excessive weight during gestation had a higher risk for post-partum weight retention (10), contributing to a larger number of women entering subsequent pregnancies as overweight or obese. Fetal outcomes resulting from excessive GWG in women of all pre-pregnancy BMI classes has been related to increased rates of birth weight greater than 4,000 grams, but in women with pre-pregnancy obesity in class I, II, or III have increased rates of neonatal metabolic abnormalities (2). In general, maternal obesity can lead to increased risk (adjusted odds ratio) for preeclampsia (4.82), stillbirth (2.79), shoulder dystocia (3.14), meconium aspiration (2.85), fetal distress (2.52), early neonatal death (3.41), and LGA (3.82) (3). These adverse outcomes may also be related to early GWG as women who gained excessive weight between weeks 15 and 18 of gestation showed increased rates of LGA, and birth weight greater than 4,000 grams compared to women who did not gain early excessive gestational weight (1).

Excessive GWG has been identified as an important public health concern. In 1990, the IOM published the first set of weight gain guidelines to prevent premature birth and low
birth weight. Recommended weight gain per BMI category was as follows: 28-40 lbs, 25-35 lbs, 15-25 lbs, and at least 15 lbs for underweight, normal weight, overweight, and obese BMI, respectively. At that time, the pre-pregnancy BMI cut-points were based on Metropolitan Life Insurance tables: \(< 19.5 \text{ kg/m}^2\) (underweight), \(19.8-26 \text{ kg/m}^2\) (normal); \(> 26-29 \text{ kg/m}^2\) (overweight), and \(> 29 \text{ kg/m}^2\) (obese) which were. From 1993-2003, according to the 1990 IOM guidelines, almost half of underweight women met weight gain recommendations, 30.6% gained inadequately, and 19.5% gained excessively. The percentage of normal weight women gaining in excess of the recommendation remained steady at around 39%. During that timeframe the percentage of overweight women experiencing excessive GWG increased from 57.1% to 63% and the amount meeting recommendations decreased from 31.2% to 26.8%. Similarly, only one third of obese women gained within the recommended weight range. These statistics continued to worsen with only 30% of women across all BMI categories meeting the 1990 weight gain guidelines in 2007 (34).

In 2009, the IOM revised the weight gain recommendations to reflect the new World Health Organization BMI cut-points: \(< 18.5 \text{ kg/m}^2\) (underweight), \(18.5-24.9 \text{ kg/m}^2\) (normal), \(25-29.9 \text{ kg/m}^2\) (overweight), and \(\geq 30 \text{ kg/m}^2\) (obese). New recommendations were established for obese women for a total GWG of 11-20 lbs. Additionally, the 2009 guidelines were established to prevent adverse postnatal outcomes associated with excessive GWG including postpartum weight retention, cesarean delivery, small- and large-for-gestational age, preterm birth, and childhood obesity. The guidelines consist of a recommended range of weight gain based on pre-pregnancy BMI, but do not account for differences in age, race, ethnicity, or environmental factors (34). Using these current
guidelines, excessive GWG is currently prevalent in approximately half of all pregnancies using the 2009 IOM recommendations (35). In terms of pre-pregnancy BMI, Carreno et al. reported early excessive GWG between weeks 15 and 18 of gestation according to BMI: 45% underweight, 46% normal weight, 54% overweight and 45% obese (1). Of all participants with early excessive GWG, 93% ended gestation with a total weight gain in excess of the IOM recommendations. In addition, 55% of participants with non-excessive early GWG exceeded total GWG recommendations (1). Other studies have revealed population rates of excessive GWG between 49-59% (7,14,24,36). These statistics have been replicated in unpublished data collected by the Campbell Lab which showed a 49% prevalence of excessive GWG. When stratified for pre-pregnancy BMI, rates of excessive GWG are reported as follows: 39-55.3% (normal weight), 65-84.2% (overweight), 56-69.5% (obese) (7,24,37). In all of the aforementioned studies, women who were overweight prior to pregnancy had the highest prevalence of excessive GWG compared to those of normal weight or who were obese.

Due to the prevalence and negative consequences of excessive GWG, it is important to identify the factors which contribute to excessive GWG so that effective prevention prenatal strategies can be developed. Since weight gain is a result of energy imbalance, lifestyle factors such as dietary intake and PA should be considered. As patterns which contribute to excessive GWG likely begin prior to pregnancy, it is important to consider the factors which contribute to weight status in the general population.
Factors that Contribute to Weight Status in Adults

A) Energy Intake

Energy balance has been well documented as a significant predictor of weight status such that energy intake greater than energy expenditure will result in weight gain (38). Aspects of energy intake known to have an effect on energy balance include excessive intake of refined carbohydrates (39), fat (40-41), and/or sugar (42), as well as consumption of alcohol (43). With obesity rates in America rising exponentially, it is evident that overconsumption is playing a significant role in the weight status of adults (44). However, the exact aspect(s) of the diet which may have the largest impact on weight continue to be debated and could ultimately be multifactorial.

In order to communicate the importance of energy intake in weight maintenance and overall health, the Dietary Guidelines for Americans (DGA) were developed. These nutritional recommendations have been revised every five years since 1980 and are designed for Americans two years of age and older as well as those who are at risk for chronic disease. The goal of the DGA is to help consumers choose nutritionally and calorically adequate, nutrient-dense foods. The current guidelines, published in 2010, work to advise the public on caloric balance while recommending an increase in fruit, vegetable, and water consumption and reducing sodium intake. Guidelines also focus on making at least half of consumed grains whole, switching to low-fat or fat-free milk, and avoiding oversized portions (45). The Healthy Eating Index (HEI) was developed as a way to assess compliance with the DGA (see Diet during Pregnancy: Diet Indices used during Pregnancy). Although the identification of specific dietary culprits that cause weight gain remains unknown,
government guidelines have been developed surrounding both diet and physical activity (PA) in an attempt to combat overconsumption and promote health.

B) Energy Expenditure

1. Physical Activity

As mentioned earlier, energy balance involves a two part system of intake and expenditure. Energy expenditure is comprised of basal metabolic rate, thermic effect of food, PA, and growth. In non-pregnant adults, the relationship between PA, a modifiable aspect of energy expenditure, and overall health, especially weight status, has been well documented in the literature. Physical activity has also been associated with the improvement of blood glucose, lipid markers, blood pressure, and overall cardiovascular health in non-pregnant populations (46).

Physical activity is defined by the DHHS as “any body movement that works your muscles and requires more energy than resting” (47). Insufficient PA has been associated with increased risk of being overweight/obese (OR 1.43) in adults (48). If insufficient PA is combined with driving 3.5-7 hours per week, the risk of being overweight increases three-fold (OR 1.73) compared to sufficiently active adults driving less than 3.5 hours per week (48). Since young adults in the U.S. tend to use less active transportation (walking, biking, etc) in comparison to inactive transportation (car, public transport, etc), they may be at a higher risk for being overweight/obese (49). Those who were overweight used less active transport than the non-overweight (49).

Multiple PA guidelines for adults have been developed, but these guidelines focus on achieving health benefits through a small amount of MVPA without regard to total daily PA.
The American College of Sports Medicine (ACSM) and the American Heart Association (AHA) recommend at least 30 minutes of moderate intensity PA 5 days per week completed in bouts of at least 10 minutes or vigorous aerobic activity for at least 20 minutes 3 days per week (50). Intensity categories are defined as follows: sedentary (< 1.5 metabolic equivalent of task (METs)), light (1.6-2.9 METs), moderate (3-5.9 METs), and vigorous (> 6 METs) (51). A position paper from ACSM further suggests, for adults of all activity levels, a reduction in sedentary behavior (SB) and short bouts of standing amidst time spent sedentary (52). The U.S. Department of Health and Human Services (DHHS) recommends at least an accumulation of 150 minutes per week of moderately intense PA or 75 minutes of vigorously intense PA done in ten minute bouts to achieve “substantial health benefits” (53). Additional time spent in moderate PA (total of 300 minutes per week), vigorous PA (total of 150 minutes per week) or in strength training (at least two times per week) is intended to achieve “more extensive health benefits” (53). The U.S. DHHS PA guidelines have been translated into steps per day with a recommendation of walking a minimum of 3000 steps in 30 minutes five days per week or completing three bouts of 1000 steps in 10 minutes each day of the week (54). These step guidelines are intended to be used in addition to activities of daily living and are to represent volitional PA. Tudor-Locke and Bassett established PA cut-points relative to steps per day: sedentary lifestyle (< 5000 steps/d), low active (5000-7499 steps/day), somewhat active (7500-9999 steps/day), active (≥ 10000 steps/day), highly active (> 12500 steps/day) (55).

Even though the PA guidelines only address MVPA, light intensity PA, defined as 1.6-2.9 METs, may also have a significant influence on health outcomes. Bell et al. observed light and moderate work-related activity to be the greatest predictors of weight gain in both
men and women (56). Healy et al. determined a significant association (b= -0.22, P = 0.023) between light-intensity activity and 2-hr plasma glucose after adjusting for moderate-vigorous activity (65).

Even with the availability of PA guidelines, it is evident that many American’s are physically active. According to the 2007 Behavioral Risk Factor Surveillance System (BRFSS) telephone survey, 64.5% of adults meet the 2008 DHHS PA guidelines of 150 minutes of moderate-vigorous PA per week (57). NHANES data from 1999-2002 showed a much lower prevalence when referring to the ACSM/AHA recommendation of at least 30 minutes moderate activity per day with adherence to the guideline in 32.6% of those trying to lose weight, 37.9% in those trying to maintain weight, and 21.8% in those not attempting to loose or gain weight (58). With obesity rates rapidly rising, it may be important to increase the focus on reducing SB and address the contribution of light PA to health in addition to promoting moderate-vigorous PA.

2. Sedentary Behavior

The Sedentary Behaviour Research Network defines SB as “any waking behaviour characterized by an energy expenditure ≤1.5 METs while in a sitting or reclining posture” (59). While SB is not a large component of total daily energy expenditure, it does constitute the majority of time per day for American adults, and therefore should be considered as a potential factor of overall health. Blair et al. suggests that meeting PA guidelines may not be adequate in the prevention of unhealthful weight gain and that it is important to consider the possible implications of behavior outside of PA, specifically time spent in SB (60). Blair also states the importance of reducing SB in relation to a reduction in mortality (61). The
current PA guidelines are aimed to increase PA, but the literature suggests the need to focus on reducing time spent in SB. Although the evaluation of SB or physical inactivity, as a contributor to overall health status has been historically addressed in the literature, the focus on SB as a public health concern is a recent development.

In order to assess time spent in SB, various cut-points have been identified for use in objective assessment. One such assessment using the ActiGraph, an accelerometer which yields activity data in counts per minute, identified 54.9% or 7.7 hours of adult and child participants monitored time (approximately 14 hours per day) was spent in SB. The Matthews cut-point or <100 counts/minute was used to define SB (62). A secondary analysis of several studies conducted in Belgium found that adults ages 18-65 (n=960) spent 55% of time awake in SB. Men spent on average about 61% of time in SB, 38% in light PA, and 5% in moderate PA whereas women spent about 58% of time in SB, 42% in light PA, and 4% in moderate PA (63). These studies capture inactivity during waking hours (monitoring of all periods awake or a set period of time such as 7 a.m. to 7 p.m.), but without 24-hour monitoring of PA and minimal off-body time, it is difficult to estimate true time spent in SB. Compared to studies based on a subjective measure of sedentary time such as time spent driving or watching television, the quantification of sedentary time through the use of an accelerometer is preferred. However, compliance and definitions of wear-time continue to be limitations to the assessment of SB.

Various studies using proxies for sedentary time focus on the health outcomes associated with inactivity. Sedentary behavior has been associated with an increased risk for metabolic syndrome (64-67), cardiovascular risk (68), and insulin resistance (69) in men, women, and children. Although television watching, used as a proxy for SB, has been
related to an increased risk for metabolic syndrome, these studies do not also account for time spent sitting beyond television watching (70-71). Healy et al. suggested that breaks in SB, such as standing up after sitting for a long time, may negate health concerns associated with inactivity. Increased breaks in behaviors, independent of total sedentary time and controlled for time spent in moderate-vigorous activity, may decrease the risk for metabolic syndrome as a result of inactivity with observed reductions in waist circumference, BMI, triglycerides, and 2-h plasma glucose (72). Swanson & McCormack observed that driving between 14 and 30 hours per week to be associated with an increased likelihood of being overweight/obese (odds ratio 2.08) compared to driving less than 3.5 hours per week. They also noted that every hour per week spent driving reduced the odd of meeting PA recommendations by 1.6% (48). Part of the explanation for an increased metabolic risk in response to inactivity may be a result of adverse effects at the cellular level as a lack of movement possibly inhibits lipoprotein lipase activity in skeletal muscle, which could alter the catabolism of triglyceride (73).

Matthews et al. observed an increased risk for mortality (all-cause, cardiovascular, and cancer) in relation to SB measured with a questionnaire to assess time spent sitting and watching television even after adjustment for time spent in moderate-vigorous activity (74). In terms of metabolic syndrome, SB has been independently associated with an increased risk after adjustment for time spent in moderate-vigorous activity (odds ratio 3.30) in women (65,70,75). Bassett and Freedson (76) stated in a recent commentary that positive associations between sedentary time (assessed via television watching) and obesity, diabetes, glucose intolerance and insulin resistance persist after adjusting for time spent in moderate and vigorous PA. Furthermore, Craft et al. demonstrated that women (n=91) ages 40-65 who
met or exceeded PA recommendations (150 minutes moderate-vigorous PA in at least 10 minutes bouts) did not spend significantly less time sitting, standing, and non-exercise stepping than women who did not meet PA recommendations (77). In effect, women who were active were still spending a significant amount of the day in SB. These findings provide evidence that participation in moderate-vigorous PA may be unrelated to total sedentary time; therefore decreasing sedentary time should be addressed independently of increasing moderate PA.

3. Sleep

Many of the studies on SB do not address behavior over a 24-hour period and therefore do not consistently consider nighttime sleep or daytime naps as a component of SB. Although sleep is a SB, it is a necessary component of health and should therefore be separated from daily SB associated with health risks. The Sedentary Behaviour Research Network specified that SB only includes time awake (59). However, daytime napping may not be considered an optimal sleep pattern and should be addressed separately from nighttime sleep. Therefore, it is important to identify proper sleep patterns in terms of duration of nighttime sleep and daytime sleep in order to account for sleep as part of activity profile over a 24 hour period. The CDC recommends between seven and nine hours of sleep per night in order to prevent chronic disease (78). At least 28% of adults sleep less than 6 hours per night (79). In women only, short (< 5 hours/night) and long sleep duration (≥ 9 hours/night) have been associated with weight gain of about 5 kg across a 5-7 year span (80). In addition, various studies of men and women have reported an inverse association between rates of short sleep duration and rates of obesity (81). Just as adequate sleep is important in non-
pregnant adults, it is crucial during pregnancy for fetal growth (82-83). Therefore, sleep in terms of duration, should be considered along with diet and PA as components of a healthy pregnancy and gestational weight gain.

**Factors that Contribute to Gestational Weight Gain**

Identified significant predictors of GWG include pre-pregnancy BMI (Begum F, 2012) (10), excessive energy intake (11), nutrient distribution (12), lack of PA (13-14) (15), and community or household environment (16-18). Pre-pregnancy PA and dietary intake have largely been the focus of past intervention and observational studies aiming to identify contributors to GWG. However, SB during pregnancy has not been thoroughly considered as a contributor to GWG and thus may warrant more attention in future research. When developing strategies to prevent excessive GWG it may be important to consider all aspects of lifestyle including diet, PA, SB, and sleep.

A) **Diet during Pregnancy**

1. **Energy Requirements**

   Energy intake is one aspect of diet which is evaluated during pregnancy with relation to maternal and fetal outcomes. Several equations exist to estimate energy requirements in pregnancy. The Dietary Reference Intakes (DRI)/Recommended Daily Allowance (RDA)/IOM values recommend 2500 calories per day during the first trimester with caloric increases of 340 and 452 calories in the second and third trimester, respectively (84). FAO/WHO/UNU recommends an extra 360 calories per day during the second trimester and 475 calories during the third trimester (85). The FAO recommendations were developed
from data on women that gained 12 kg during pregnancy, did not seek prenatal care until after 5 weeks of gestation, and live in an area with a high proportion of non-obese women (85). The IOM published an equation in 2005, also referred to as part of the DRIs, which accounts for age, PA level, weight, height, and BMI, and provides an extra eight calories per week of gestation starting in the second trimester (e.g. 8 kcal per day times 12 weeks of gestation beyond 1\textsuperscript{st} trimester – provides an extra 160 kcal per day) (84).

2. Energy Intake during Pregnancy

Various studies using different measures of diet have reported dietary intake during pregnancy (10,86-92). In addition to the prevalence of under-reporting, several studies report dietary intakes during pregnancy from only 2\textsuperscript{nd} (92) or 3\textsuperscript{rd} (87,89) trimester, as an average between several (10,90-91) or all trimesters (88), or do not identify gestation period (86); thus, it is difficult to determine actual intake per day for each trimester.

Two studies reported average energy intake across the entire gestation period (86,88). Turner et al. used 1, 3-day diet record per month, starting in the first trimester of gestation, in middle to upper-income women and found a median caloric intake of 2,210 kcals/day with the 25\textsuperscript{th} percentile at 1,913 kcals/day and the 75\textsuperscript{th} percentile at 2,327 kcals/day (88). Blumfield et al. used a 74-item food-frequency questionnaire (FFQ) with Australian women (n=606) during their pregnancy, and determined average intake to be 1720 kcals when participants with an intake less than 1075 kcals/day or greater than 4777 kcals/day were excluded from analysis for misreporting (86).

Other studies using FFQs note mean caloric intakes between 1839 kcals/day in English women to 3168 ± 1098 kcal/day in Australian women during the third trimester (86-
87). However, these studies have recognized the prevalence of under-reporting (estimated to be about 38%) (87) and the lack of representation from a usual intake using only a single FFQ (86). Under-reporting has been defined as participants whose reported intake amounted to less than 120% of their basal metabolic rate (calculated using Schofield’s equations) (87). McGowan and McAuliffe have estimated that as many as 45% of women may be under-reporting their intake during early pregnancy. In addition, it is possible that there is an association between under-reporting and decreased likelihood of meeting dietary recommendations during pregnancy as was demonstrated in an Irish population (93). Under-reporters have been previously been defined as participants with a ratio of energy expenditure (SWA) to reported energy intake as greater than 1.2 (94-96). Since dietary intake during pregnancy is often evaluated in relation to excessive GWG, it is important to consider under-reporting as it may cause diet to have a less significant association with weight gain.

A cohort of the Project Viva study (n=780), reported average energy intake between first and second trimester (estimated using a semi-quantitative FFQ, modified for pregnancy) to be 2135 ± 596 kcals (90). Siega-Riz et al. also reported a median estimate of 2478 kcals/day using a FFQ administered during the 2\textsuperscript{nd} trimester (92). Unpublished data from the Campbell Lab also demonstrated women are consuming 2084 ± 467 kcals/day during their second trimester and 2207 ± 595 kcals/day during their third trimester using 3-day weighed diet records (original Blossom Project). Additionally, Giddens et al. found energy intake to be 2134 ± 498 kcals/day using an average of 7-day food records from the second and the third trimester (91). Although two studies have reported no significant difference between energy intake during the 2\textsuperscript{nd} and 3\textsuperscript{rd} trimester, the lack of separate analysis for the 2\textsuperscript{nd} and 3\textsuperscript{rd}
trimester makes it difficult to compare current prenatal intake to recommendations (91). Cohen et al. also found no significant difference between intake during the second and third trimester with reported intakes of 2231 ± 553 kcals/day and 2242 ± 480 kcals/day, respectively (97). Using 2, 5-day food records, Finnish women were estimated to consume 2173 ± 430 kcals/day during the 3rd trimester (89). The aforementioned studies show consistent energy intake across pregnancy, which will affect prenatal outcome regardless of excess or inadequate consumption.

3. Diet and Birth Outcomes

Although energy intake has been reported to insignificantly change across pregnancy, it is known to be a significant predictor of GWG when subjectively ‘much more’ or ‘much less’ than prior to pregnancy (11). Gestational weight gain is associated with infant birth weight (r=0.32) and post-partum weight retention (r=0.72) in women consuming between 1079 and 3763 kcals/day, 54% of whom were consuming in excess of their estimated energy needs (10). Maternal diet may also have an effect on the risk of preterm birth, specifically in terms of meal patterns with less frequent eating increasing risk of preterm birth independent of total energy intake (20-21). Both a high carbohydrate intake (> 340g/day) early in pregnancy and a low intake of dairy and meat protein (≤ 76 g/day) late in pregnancy, have individually been associated with lower placental and birth weights (12). Low placental weight indicates suboptimal nutrition transferred to the fetus and can thereby result in impaired fetal growth. In order to achieve proper maternal and fetal growth, nutritional guidelines should be followed and diet should be composed of high quality, nutrient-dense foods.
4. Diet Indices used during Pregnancy

Diet quality reflects adherence to dietary recommendations of a population in terms of food groups and micronutrients. Compared to evaluating dietary intake based on calories, macro- and micronutrients, diet quality reflects the nutrient density of the foods consumed.

Several indices have been published in order to identify diet quality in the general population, but have also been applied during pregnancy. The HEI (addressed in Factors that Contribute to Weight Status in Adults: Energy Intake), developed by the USDA to score American diets with reference to the Dietary Guidelines for Americans, was initially developed in 1989 and has since been updated in 1994, 1999, 2005, and 2010. The HEI 2005 (HEI-05) reflected the updated Dietary Guidelines for 2005 to evaluate diet quality based on the consumption of total fruit, whole fruit, total vegetables, dark green/orange vegetables and legumes, total grains, whole grains, milk, meat and beans, oils, saturated fat, sodium, and calories from solid fats, alcoholic beverages, and added sugars (98). Most recently, the HEI 2010 has been released to update the HEI-05 to mirror the 2010 Dietary Guidelines for Americans. The most notable changes in the HEI 2010 are as follows: 1) “Dark Green and Orange Vegetables” (HEI-05) were replaced with “Greens and Beans”; 2) a “Seafood and Plant Proteins” category was added; 3) “Oils and Saturated Fat” (HEI-05) was replaced with a ratio of polyunsaturated and monounsaturated to saturated fatty acids; and 4) “Total Grains: (HEI-05) was replaced with “Refined Grains” (in addition to the already existing Whole Grains category). The HEI-05 has been used to demonstrate a decrease in diet (assessed from a food frequency questionnaire) quality score from early pregnancy (weeks 10-20: 56.7 ± 10.1) to second trimester (week 28: 54.0 ± 10.3) in overweight (n=136) and obese (n=155) women (99).
An alternate healthy index (AHEI), based on the HEI-05 was developed to increase predication rates of chronic disease by incorporating food groups and characteristics associated with a decreased chronic disease risk. The AHEI differs from the HEI-05 in that it addresses the ratio of white to red meat, cereal fiber, fat quality, duration of multivitamin use, and number of servings of alcohol per day. High scores on the AHEI have been associated with decreased risk of cardiovascular disease and type 2 diabetes, as well as decreased biomarkers of inflammation and endothelial dysfunction (100).

Two indices have specifically been developed for use during pregnancy. The Alternate Healthy Eating Index for Pregnancy (AHEI-P) is a modified version of the Alternate Healthy Eating Index. The AHEI-P was modified from the AHEI to include food sources of folate, calcium, and iron. A study using the AHEI-P to assess diet quality based on a food frequency questionnaire in a Project Viva US cohort of women during their first trimester revealed an average score of 61 ± 10 out of a possible 90 points. Worse scores were associated with a higher BMI (-0.9 points per increase in 5kg/m²), less education (-5.2 points for a high school degree or less versus college degree), and more children (-1.5 points per child). Every five point increase in an AHEI-P score from the first or second trimester was associated with a 0.64 mg/dL reduction in blood glucose. Additionally, each five point increase in AHEI-P from the second trimester was related to a lower risk of preeclampsia (odds ratio 0.87) (101). The AHEI-P has also been used to reflect diet quality during the first trimester in Spanish women revealing an association between diet quality in the highest quintile and a reduced risk of low birth weight (odds ratio 0.24) (102).

The Dietary Quality Index for Pregnancy (DQI-P) was developed and published in 2002 to reflect prenatal recommendations at that time as well as the 2000 DGA. The DQI-P
score depends on the adequacy of meeting the recommended number of servings of grains, vegetables, and fruits according to caloric categories from the Food Guide Pyramid. Additionally, the DQI-P provides a score for folate, iron, calcium, and fat intake as well as meal pattern in terms of number of snacks and meals consumed. Lower DQI-P scores ($\leq 57$) were associated with less than 30 years of age, multiparous, and individuals without a high school degree (103).

The Dietary Quality Index for Pregnancy (DQI-P) fails to define a meal versus a snack making the application of the DQI-P to future studies problematic. In addition, by not separating total fat intake into subgroups, it is difficult to identify specific connections between diet composition and health outcomes. Lastly, the DQI-P does not account for food groups which are combined in a mixed dish potentially making this tool less applicable to certain populations. The DQI-P, while a possibly effective assessment tool near the time it was published in 2002, is now dated since it uses the Food Guide Pyramid for a reference standard and therefore does not reflect current prenatal caloric recommendations. The Alternate Healthy Eating Index for Pregnancy (AHEI-P) did not account for consumption of grains and did not account for processed white meat (e.g. chicken or turkey lunchmeat) since all processed meats were considered to be red meat. In addition, the AHEI-P did not include a component for nut protein (e.g. peanut butter) which has been noted to be a highly consumed food among former Blossom Project participants. Based on the aforementioned limitations, the HEI appears to be the most appropriate dietary index for use in pregnancy. Diet quality during pregnancy is important to address, as the quality of calories consumed may contribute to overall health and GWG independent of energy intake.
B) **Physical Activity during Pregnancy**

In addition to the effects of diet in terms of energy intake on GWG, PA is another modifiable lifestyle factor which should be addressed. Although there is sufficient evidence to demonstrate that PA during pregnancy is safe (104-108), the exact quantity, quality, frequency, and duration of PA needed to achieve a certain health outcome during pregnancy have yet to be determined. Several entities have published weekly PA recommendations for pregnancy, yet the lack of consistency among guidelines confirms the need for clarity and further research on PA during pregnancy.

1. **Physical Activity Recommendations during Pregnancy**

The DHHS 2008 guidelines for pregnancy of 150 minutes of MVPA per week are similar as those for non-pregnant adults except that the recommendations do not specify that the moderately intense PA be completed in at least 10 minutes bouts (53). The American College of Obstetricians and Gynecologists recommend that pregnant women engage in at least 30 minutes of moderate PA per day on most days of the week (109). The Canadian PA Guidelines for pregnancy recommend an accumulation of 150 minutes of moderate-vigorous activity completed in 10-minute bouts (110). Smith and Campbell demonstrated that reports of PA during pregnancy vary significantly depending on which recommendation was used. Adherence to guidelines ranged 5%-100% at week 18 and 9%-100% at week 35 of gestation (111). Published guidelines for PA during pregnancy are intended to provide recommendations which will positively impact health during pregnancy. However, it is crucial that guidelines are interpreted unanimously to allow for comparable research outcomes.
2. Physical Activity and Maternal/Fetal Outcomes

Regular PA, defined as at least three days per week of moderate activity, has been shown to reduce the risk of GDM (22-23), pre-eclampsia (24-25), and pre-term birth (26-28). Women who participate in vigorous activity (≥ 6 METs) before pregnancy and continue with any type of PA during pregnancy have a lower risk of developing GDM and abnormal glucose tolerance (22). The participation in vigorous PA during pregnancy has also been inversely associated with risk for GDM (112). Physical activity has been documented as a potential strategy to reduce excessive GWG (13-15,29-30). Moderately intense (30% heart rate reserve) prenatal exercise three to four times per week has been shown to reduce the risk of excess weight gain in women who were overweight prior to pregnancy (13).

Consequently, as activity levels increased from sedentary to active, the risk for excessive GWG decreased (adjusted odds ratio 1.00, 0.59, respectively) (14).

Moderately intense exercise during pregnancy has been shown to slightly decrease the risk for small and large for gestational age infants (113-114), and preterm birth (26,28). Both et al. found no association between physical exertion and gestation duration, but did find a reduced risk (adjusted odds ratio 1.25) of preterm birth with ‘bending and stooping’ during the third trimester (27).

Although benefits between regular PA and birth outcomes have been identified, the aforementioned studies only describe frequency and type of activity from questionnaires, leaving duration to be assumed. Fleten et al. demonstrated the relationship between exercise frequency and birth weight with an increase of one time per month related to a 2.9g decrease in birth weight. An association between BMI and birth weight was also explained by a 20.3g increase in birth weight for every increase of 1 kg/m² in BMI (115). Furthermore, Juhl et al.
found only a modest decreased risk of small- (hazard ratio 0.87) and large-for-gestational-age
(hazard ratio 0.93) infants with women who exercised compared to those who did not (113).

There are only several randomized control trials that have been conducted with PA
during pregnancy in relation to maternal and fetal outcomes. An at-home exercise program
beginning at week 20 of gestation and continuing through delivery showed a decrease in
offspring birth weight compared to the control group which maintained normal daily activity
(sd score: -0.19 ± 0.9 (exercise), 0.23 ± 0.8 (control); P = 0.03) (116). Reductions in
maternal insulin sensitivity were not attributed to long-term prolonged exercise, which is
suggested to be a result of an acute insulin response following exercise (116). Previously
sedentary women defined as no aerobic exercise of any duration more than once per week for
the past 6 months) were randomized to an active (n=43) or inactive group (n=43) beginning
at weeks 12-14 of gestation. Those in the active group completed 45-60 minutes of
supervised, moderate PA 4-days per week of a variation of step aerobics, walking, and circuit
training with weight lifting and suing an a elliptical or stationary bike. Those in the inactive
group were told not to exercise and were required to verbally reconfirm their inactivity every
6 weeks. The active group showed significantly improved aerobic fitness, muscular strength,
had fewer cesarean deliveries and a faster postpartum recovery compared to the inactive
group. However, no difference in the incidence of GDM or GWG was observed (117).
Haakstad and Bø observed a significant decrease in GWG) with participation in at least one
hour of cardio and strength exercise twice per week for at least 12 weeks. However, the
number of women who participated in the exercise program and met the 2009 IOM GWG
guidelines did not differ from the control group (118). Although PA during pregnancy has
been recognized as beneficial and effective as a preventative measure for reducing risk for
prenatal complications, there are few studies which demonstrate that PA or a certain intensity and/or duration influences GWG or leads to other health benefits.

3. Physical Activity Prevalence during Pregnancy

The prevalence of excessive gestational weight gain, which leads to adverse maternal and fetal outcomes, may be related to the low prevalence of women meeting current prenatal PA guidelines. The number of pregnant women meeting prenatal PA recommendations varies widely based on the type of assessment measurement used (objective vs. subjective) or how the data was interpreted (cumulative minutes in moderate PA vs. minimum bout of moderate PA). It is also important to note that participation in PA during pregnancy is largely affected by time constraints, fatigue, nausea, lack of child care, presence of familial support, and the ability to find joy in being active (119).

Results from the Center for Disease Control’s Behavioral Risk Factor Surveillance System (BRFSS) data from 2000 revealed 16% of pregnant women completed at least 3, 20 minute bouts of vigorous leisure activity or 5, 30 minute bouts of moderate leisure activity (120). Similarly, data from the 1999-2006 National Health and Nutrition Examination Survey (NHANES) reveals 23% of pregnant women met moderate-vigorous activity recommendations of at least 150 minutes (121). Studies using objective assessment methods demonstrate that 11-14% of women achieved PA recommendations when assessed with an accelerometer (122) or a pedometer (123). Conversely, other studies (124-126) report a much higher prevalence. A retrospective survey administered 6-32 months postpartum reported approximately 50% of women exercised during pregnancy (124) and the Avon Longitudinal Study of Parents and Children had nearly 50% of women report at least 3 hours of strenuous
activity (defined as activity that induced sweating) during the 18th week of gestation (125). Additionally, McParlin et al. (126) identified 62-71% of pregnant women achieving at least 30 minutes of MVPA per day at 13, 26 and 36 weeks of gestation according to accumulated MVPA occurring throughout the day (as reported by an accelerometer). Furthermore, data from our laboratory suggests that the interpretation of accelerometer data can lead to varying interpretations of the prevalence of PA (127). Smith et al. (127) found that 13 out of 52 women met PA recommendations per participant interview however 42 out of 52 women met recommendations per the SWA pattern recognition monitor when time spent in moderate PA was totaled for the day. Many women may not be participating in volitional exercise, but due to the inconsistency in interpretation of the PA recommendations and/or the method of PA assessment, it is difficult to identify the prevalence of prenatal PA.

4. Physical Activity Patterns during Pregnancy

Although the prevalence of PA during pregnancy is unclear, various studies report a significant decrease in PA from the second to third trimester of pregnancy (128) (121,129). These findings are consistent regardless of assessment material used to determine physical activities during pregnancy including a one week recall (128), self-report via interview or questionnaire (123,130-131), accelerometer (129), and pedometer (123). Changes in PA are often not assessed during the first trimester, as activity during this time is commonly altered by nausea and fatigue. It is important to identify PA as a portion of daily behavior during each trimester individually. This allows for behaviors throughout the rest of the day to be quantified while considering change in daily composition of behavior across pregnancy.
C) Sedentary Behavior during Pregnancy

Physical activity recommendations during pregnancy entail guidelines on participation in moderate PA most days of the week. However, little attention has been given to the activity that comprises the remainder of the day, which is as much as 23 hours and 30 minutes when referring to the AGOG recommendations of 30 minutes of activity per day. As mentioned in section titled, “Energy Expenditure: Sedentary Time”, SB is associated with metabolic syndrome, cardiovascular risk, insulin resistance, and increased risk of being overweight/obese in the non-pregnant adult population. Evenson and Wen analyzed the prevalence of SB using 2003-2006 NHANES data for 359 pregnant women wearing an ActiGraph accelerometer and found the women spent 57.1% or 7 hours of their monitored time (all time awake) in SB (31). Considering that maternal weight status during pregnancy can influence the future health of the baby, it is imperative that the evaluation of the relationship between PA and pregnancy include the measurement of SB. This will allow for appropriate conclusions to be made between the relationship between prenatal PA and maternal/infant health outcomes.

Sedentary behavior may contribute to excessive gestational weight gain. Both et al. (27) observed a small, significant association between a sedentary lifestyle (assessed with a subjective instrument) and lower birth weight (27). Gollenberg et al., used interviews and quantitative analysis with quartiles, to demonstrate that increased total SB (odds ratio 0.72) as well as low participation in exercise (odds ratio 2.01) in Latina women was associated with an increased risk for abnormal glucose tolerance mid-pregnancy (132). Oken et al. did not find any association between inactivity and abnormal glucose tolerance when SB was assessed using time spent watching television as a proxy (22). However, the use of a proxy
for inactivity did not account for other occupational or leisurely SBs such as sitting at work or working on a computer. Using a questionnaire, Zhang et al. found that pregnant women who spent more than 20 hours/week watching television and did not participate in vigorous PA had a greater than two times the risk for developing GDM than those who watched television less than 2 hours/week and were in the highest quintile of vigorous PA (relative risk: 2.30, p = 0.71 for interaction) (112). Conversely, Van der Ploeg et al. did not find an association between risk of GDM and SB (measured by questionnaire of time spent sitting) (133). Jiang et al. reported 40% lower prevalence of excessive GWG in the active group (≥ 10,000 daily steps) compared to the sedentary group (≤ 5000 daily steps) (14). Gradmark et al. (134) assessed PA including SB with an accelerometer (Actiheart monitor) and only found a significant association between improved insulin sensitivity and increased total (sedentary, light, moderate, and vigorous) PA ($R^2 = 0.11, P = 0.007$), rather than an association with just moderate-vigorous PA. Since previously reported associations of PA and health benefits address the role of moderate-vigorous PA, evidence of the effect of light PA on health during pregnancy should be further investigated. Pregnant women were also estimated to spend 13% more time sedentary and 71% less time in moderate to vigorously intense PA than non-pregnant women (134). If pregnant women are spending at least 57 percent of their time awake in SB (31), it is imperative that SB be included as a possible factor related to gestational weight gain.

D) **Sleep during Pregnancy**

To date, there is a limited amount of research on sleep duration and efficiency (rapid eye movement (REM) sleep versus non-REM sleep) during the prenatal period, or on the
consequences for maternal and fetal health. Especially when considering the impact of lifestyle (diet, exercise, and SB) during pregnancy, it is important to account for sleep as part of the day. As mentioned previously, very few studies on SB in the general population or in pregnancy monitor hours spent asleep at night.

Pregnancy is often accompanied by poor sleep quality, decreased sleep duration, difficulty falling asleep, and decreased sleep efficiency which is largely attributed to hormonal changes during pregnancy, and growth of the fetus (135-136). Borodulin and colleges reported that only 61.3% of women (n=1259) during their second trimester were sleeping between 7-9 hours per night as per questionnaire, the recommended amount for adults (137). Towards the end of pregnancy, sleep has reported to become more fragmented and of lower subjective quality (138). This could lead to sleep deprivation (<5 hrs/night), which if occurs during the third trimester, could increase the risk for preterm birth (82).

Sleep across pregnancy has been observed, using questionnaires, to decrease from second to third trimester with averages similar to those reported above (139-140). The findings from the lab study are still in agreement with trends from previous studies using polysomnography and questionnaires that showed women have disrupted sleep patterns starting in the first trimester and continuing throughout pregnancy (138-141).

The sleep pattern during pregnancy most optimal for maternal and fetal health is unknown. Thus far, maternal sleep patterns, in terms of daytime sleep during the last month of pregnancy, have been associated with an increased prevalence of still birth (83). It has also been recently suggested that reduced sleep duration during pregnancy may play a role in carbohydrate metabolism by reducing insulin sensitivity possibly related to a hormonal response leading to increased blood glucose and increased risk for GDM (142). Sleep is an
important aspect of behavior as it contributes to maternal and fetal growth and metabolism, and may also impact gestational weight gain.

Prevention of Excessive Gestational Weight Gain

The identification of diet and exercise as modifiable risk factors for GWG (33) has led to various randomized control trials during pregnancy. Interventions focused on overweight and or obese women have had success in reducing excess GWG with nutrition and exercise (13,143). Motolla et al. evaluated the effectiveness of a Nutrition and Exercise Lifestyle Intervention Program (NELIP) on GWG in 65 overweight and obese women and birth weight. The intervention began between weeks 16-20 of gestation and included an individualized nutrition plan (2000 kcal/day, 40-55% energy from carbohydrate) and a walking program. Weekly feedback was provided through the completion of a 1-day diet record. The exercise program consisted of walking three to four times per week at a low intensity (30% of heart rate reserve) while gradually increasing exercise duration by 2 min each week from 25 minutes in the first week until 40 minutes was achieved and then maintained each week thereafter until delivery. Results showed that 80% of the participants did not gain excessive gestational weight, yet there was no significant difference for gestational age or birth weight between the intervention group or the historical control matched for age, pre-pregnancy BMI and parity (n=260) (13).

Another very similar study conducted in Motolla’s Lab started between weeks 16-20 of gestation but with normal weight women who were randomized to a low- (30% heart rate reserve; n=23) or moderate-intensity (70% heart rate reserve; n=26) exercise program (29). All participants followed a modified GDM meal plan in order to control for nutrition, and a
historical control was used (n=45). The modified GDM diet consisted of 2000 kcals/day, 40-55% of total energy from carbohydrate, 30% of total energy from fat, and 20-30% from protein. The results showed significantly higher GWG in the control group (18.3 ± 5.3 kg) compared to both the low- (15.3 ± 2.9 kg; P = 0.01) and moderate-intensity (14.9 ± 3.8 kg; P = 0.003) groups over the entire pregnancy. However, weekly weight gain, calculated from the start of the intervention to delivery, was not significantly different between intervention groups. This intervention was successful in preventing GWG in 70% of participants in the low-intensity group and 77% in the moderate-intensity group (29). Both Motolla et al. (13) and Ruchat et al. (29) reported participants gained excessive GWG prior to the intervention, indicating that these types of interventions should ideally begin in the first trimester.

Hui et al. also observed a reduced prevalence of excessive GWG (control: 48% of participants; intervention: 36% of participants) when a diet counseling and home exercise intervention was provided between 20 and 36 weeks of gestation in women with various BMIs). In addition dietary intake improvements were seen two months into the intervention (n=102) with a significant lower caloric (1991 ± 458 vs 2416 ±848 kcal), fat (62.5 ± 24.4 vs 86.8 ± 36.2 g), saturated fat (19.7 ± 9.2 vs 29.2 ± 13.2 g), and cholesterol (208 ± 104 vs 323 ± 220 mg), intake compared to the control group (n=88) (30).

Lifestyle intervention involving counseling only and not a direct exercise regimen may be less effective on the prevention of excessive gestational weight gain. Kinnenun et al. examined the effects on GWG by comparing counseling as part of usual care with intervention counseling on GWG, PA, and diet during five visits. Women entered the program between weeks 8 and 12 of gestation and exhibited at least one risk factor for GDM. The intervention group (n=219) gained less gestational weight than the usual counseling
group (n=180) on a weekly basis (-0.016 kg per day, P = 0.041), but total GWG did not differ between the two groups (13.7 ± 5.8, 14.3 ± 5.0kg, P = 0.64). Compared to the usual care group, the intervention group did not have a significantly higher prevalence of participants meeting GWG recommendations (25.9 vs 27.8%) (144). These outcomes are substantially lower than those of the previously mentioned interventions possibly indicating the limited effects of counseling and further benefits of engaging participants in the activity rather than discussing an exercise regime.

Guelinckx et al. evaluated dietary intake with a 7-day diet record each trimester beginning in the first trimester for 3 groups: those who received nutrition education face-to-face (n=42), those who received education via brochure (n=37), and a non-historical control group (n=43). A decrease in saturated fat (P = 0.044) and an increase in protein intake (P = 0.033) from first to third trimester were observed in the active nutrition education and education via brochure groups compared to the control. However no significant differences in GWG were seen. This provides evidence that the method of trying to induce lifestyle change is important when considering the prevention of excessive GWG (145). Although several GWG interventions have been successful, the most effective strategies for the prevention of excessive GWG in terms of education, duration, PA intensity, and time of intervention have yet to be determined.

**Blossom Project 2**

Although interventions combining diet and exercise have been successful in reducing the prevalence of excessive gestational weight gain, there is still room for improvement. With the growing prevalence of inactivity, the concept of reducing SB separately from
increasing moderate-vigorous PA is an important next step as it relates to the prevention of excessive gestational weight gain during pregnancy. In addition, the information available on the role of sleep in regards to the assessment of SB is very limited. Considering the documented changes in sleep patterns during pregnancy, this is an important component of the day in addition to time spent in SB and moderate-vigorous activity. In order to gain a complete perspective of the effects of lifestyle on gestational weight gain, aspects of diet quality and PA/inactivity patterns should be considered.

One such way to address characteristics of diet and PA simultaneously with relation to gestational weight gain is via cluster analysis. The purpose of the following studies was to predict a pregnancy outcome such as GWG or GDM in women grouped by aspects of lifestyle or demographic. Walker created five clusters of low-income women (n=247) based on pre-pregnancy BMI, GWG, and 12 month post-partum weight retention. The following clusters of women were identified: 1) normal pre-pregnancy BMI, high GWG, average post-partum weight retention; 2) normal pre-pregnancy BMI, low GWG, no post-partum weight retention; 3) higher end of normal pre-pregnancy BMI, high GWG, high post-partum weight retention; 4) obese pre-pregnancy BMI, low GWG, average post-partum weight retention; and 5) overweight pre-pregnancy BMI, very high GWG, very high-partum weight retention. All clusters different in GWG except cluster 1 and 3, with the highest prevalence of excessive GWG in cluster 5 (100%) and 3 (88.7%), and the lowest prevalence in cluster 2 (12.5%) (146). Galjaard et al. evaluated the following clusters of obese and non-obese women (n=325) from 15 weeks to delivery to determine predictors for fetal growth and birth weight: 1) no GWG; 2) GWG of less than or equal to 4 kg; 3) GWG of between 4-12 kg; and 4) greater than 12 kg of GWG. Fetal growth and birth weight were significantly different
across all clusters except between cluster 2 with each cluster 2 and 3. The highest birth weight was seen in cluster 4 and the lowest in cluster 2, however it was also demonstrated that pre-pregnancy BMI was a significant predictor of these birth outcomes (P < 0.001).

The results of the aforementioned studies demonstrate the importance of using clustering analysis to predict birth outcomes and lifestyle patterns which lead to excessive gestational weight gain. Following the identification of factors which predict GWG, clustering will allow for multiple lifestyle factors to be considered in relation to an outcome. Thus, the aim of the Blossom Project 2 was to determine collective lifestyle factors including sedentary behavior, physical activity, and dietary quality/composition to predict GWG.
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CHAPTER 3. DISTRIBUTION OF TIME SPENT IN PHYSICAL ACTIVITY AND SEDENTARY BEHAVIORS DURING PREGNANCY: A LONGITUDINAL ANALYSIS WITH DETAILED OBJECTIVE MONITORING

A paper to be submitted to the Medicine and Science in Sports and Exercise

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Abstract

PURPOSE: The purpose of this study was to quantify habitual PA and SB during pregnancy. METHODS: During their 2nd and 3rd trimester, 46 pregnant women wore 2 PA monitors for 1 week, 24-hours per day, to provide estimates of postural allocation and steps per day (activPAL™); and sleep duration and total activity (sedentary, light, moderate, and vigorous) (SenseWear® Mini Armband). Differences in activity profiles between the 2nd and 3rd trimester were examined with paired t-tests or Wilcoxon rank-sum tests; all variables were reported in medians (25th-75th percentile). RESULTS: During the 2nd trimester, 29% or 6.8 (6.2-7.3) hr·d⁻¹ of a woman’s day was nighttime sleep; 53% or 12.7 (12.1-13.6) hr·d⁻¹ was SB; 13% or 2.9 (2.1-4.1) hr·d⁻¹ spent in light PA; 3% or 37.2 (18.7-61.1) min·d⁻¹ in moderate PA; and 0% or 0.83 (0-6.1) min·d⁻¹ in vigorous PA. A significant decrease in light PA (P < 0.05), vigorous PA (P < 0.05), and steps per day (P < 0.0005) as well as a trend in increased SB (P = 0.068), was observed in the 3rd trimester. Activity of all other intensities and sleep duration did not significantly change across pregnancy. Only 39% and 37% of participants met sleep recommendations of 7-9 hours per night at week 18 and 35, respectively. Sixty-five percent (n=30) and 61% (n=28) of participants met prenatal PA guidelines (i.e. accumulating ≥ 150 minutes moderate PA/week) during the 2nd trimester and during the 3rd trimester,
respectively. **CONCLUSION:** Pregnant women spend most of their day in SB regardless of meeting PA recommendations. The decline in total activity across pregnancy can be attributed to a reduction in light PA and an increase in SB. Additionally, the majority of women did not sleep at least 7 hours per night. The use of objective monitors over consecutive 24-hour periods provides a comprehensive synopsis of PA and SB. Further research may be warranted to measure the impacts of reducing SB and increasing total PA to prevent excess gestational weight gain.

**Introduction**

An infant’s risk of developing chronic disease later in life is a direct result of the intrauterine environment established during pregnancy. Therefore, maternal health is a predictor of an infant’s future risk of developing obesity (10,50), neonatal metabolic abnormalities (9). With chronic disease on the rise, preventative strategies are needed in prenatal care. Physical activity (PA) during pregnancy has been identified as an effective strategy to reduce the risk of prenatal complications which increase the risk for future chronic disease such as excessive gestational weight gain (GWG) (34,36,46,54,59), GDM (13,47), pre-eclampsia (11-12,65), pre-term birth (4,37,48), large- and small-for-gestational age infants (9,38,50), and abnormal glucose tolerance (7,47).

Although several benefits of PA during pregnancy are well documented, about 25% of women (17) meet the 2008 Department of Health and Human Services prenatal PA guidelines of at least 150 minutes of moderate PA spread throughout the week (62). Thus far, increasing moderate PA recommendations has been the focus of interventions to prevent excessive gestational weight gain (27,46,51,54). However minimal attention has been given
to the contribution of behaviors throughout the rest of the day outside of moderate physical activity.

Non-exercise activity thermogenesis (NEAT) represents energy expended from behaviors as part of activities of daily living other than volitional PA or exercise of moderate-vigorous intensity, sleeping, eating, and sedentary behavior (41). NEAT, specifically light activity generated from daily tasks, increases metabolic rate and thus is an important factor in the regulation of body weight (41). To our knowledge, there are no previous reports of NEAT in pregnancy despite recognition of future research needed in this area (16).

In addition to the role of light activity, sedentary behavior (SB) represents a large portion of daily behavior. According to The Sedentary Behaviour Research Network, SB is defined as “any waking behavior characterized by an energy expenditure $\leq 1.5$ METs while in a sitting or reclining posture” (56). Increased time spent in SB has been identified as a risk factor for metabolic syndrome (20,30,33,64), cardiovascular risk (43), and insulin resistance (32) in non-pregnant adults. An increase in SB during pregnancy has been associated with perinatal health outcomes including lower birth weight (4), abnormal glucose tolerance (25,47), increased risk for gestational diabetes mellitus (47,63,66), decreased insulin sensitivity and increased secretion (26), and excessive GWG (36). A limitation to the current literature on SB during pregnancy is the common use of subjective methods to assess SB (4,25,47,63,66) which may underreport SB. Also, nighttime sleep is inconsistently accounted for as a portion of total SB (18,26,36). Although sleep is a SB, it is necessary for optimal health and should therefore be separated from total daily SB which is considered to be detrimental to health. The separation of nighttime sleep from total SB allows for a more
accurate representation of daily SB during time awake as a percentage of the day. In addition, instruments used for objective measurements in the aforementioned studies allow for potential misclassification of off-body time as SB, and are not appropriate for use during pregnancy due to placement on the hip (14).

To assess habitual patterns of both prenatal PA and SB, activity should be monitored during multiple 24-hour periods. To our knowledge, this is the first study to assess SB during pregnancy using the activPAL\textsuperscript{TM}, an accelerometer designed and validated for this use (15). Therefore, the primary purpose of this prospective, longitudinal study was to objectively quantify habitual PA and SB in women with a low-risk pregnancy.

**Methods**

**Participants**

Healthy pregnant women were recruited from local obstetric clinics, advertisements, campus-wide emails, and a partnership with a large hospital in a nearby city. Fifty-six women, were enrolled in the prospective, longitudinal study at week 18 (± 1 week) of gestation. Inclusion criteria included 18-45 years of age and singleton pregnancy whereas the exclusion criteria included smoking during pregnancy or a history of chronic disease. Eight women did not complete the study for the following reasons: time constraints (n=6), skin irritation from an activity monitor (n=1), and pre-term delivery (n=1). Additionally, two women had inadequate wear time (see SenseWear\textsuperscript{®} Activity Monitor) and were excluded from analysis at both study time points for all monitors. Thus, 46 complete data sets were assessed against criteria for valid data for each objective measurement of PA (Figure 1).
Study Design

Data collection occurred at week 18 (± 1 week) and week 35 (± 1 week) of gestation. Each participant collected data for seven consecutive days during each time period. No advice was provided during the study regarding prenatal exercise. Each participant’s height (Ayrton 226 Hite-Rite Precision Mechanical Stadiometer, quick Medical GS, Snoqualmie, WA) and weight without shoes or bulky clothing (Detecto Model 6855 Cardinal Scale, Manufacturing Co., Webb City, MO) were measured and recorded at enrollment. Participants also provided a medical history and signed documents allowing for communication with their medical provider to confirm qualification criteria. Instructions for recording PA in a 7-day record and how to wear the two activity monitors (SenseWear® Mini armband (SWA), and activPAL™ (AP)) were discussed with each participant verbally and a written copy was additionally sent home. During the second data collection period (week 35), the participant’s weight measurement and all instructions on how to collect PA data were repeated.

Physical Activity Assessment

Each participant was instructed to wear the 2 PA monitors for 7 days, 24 hours a day except when showering or swimming. To control for differences in the time of day participants began wearing the monitors, data analysis was standardized to represent 6, 24-hour periods beginning and ending at midnight on the 1st and 6th day the monitors were worn, respectively.
**SenseWear® Activity Monitor**

The SWA (BodyMedia, Pittsburg, PA) is an accelerometer-based activity monitor worn on the left arm over the triceps muscle that integrates data from sensors which detect skin and near-body ambient temperature, heat flux, and galvanic skin response with data from a triaxial accelerometer. Data was downloaded using version 8.0 of the BodyMedia software (algorithm v5.2h). An excel code was written to categorize minute epochs into sleep, sedentary (≤ 1.5 METs; independent of nighttime sleep), light (1.6-2.9 METs), moderate (3-5.9 METs), and vigorous (≥ 6 METs) PA to provide estimates of total EE (1,49). Good agreement between SWA estimates of EE and measured EE using an indirect calorimeter has been previously reported at mid-pregnancy using an earlier algorithm (version 5.2e; R² = 0.71) (57). These analyses have been repeated to show improved agreement and no systematic bias using the most current algorithm (version 5.2h) (unpublished data).

An advantage of the SWA is that the monitor automatically detects off body time (OBT; e.g. due to showering or swimming); information from the physical activity record (PAR) can then be used to account for the activity that occurred during OBT. A valid day was defined as less than 72 minutes of OBT (55) and at least four valid days were required to estimate EE and assess time spent in SB, light, moderate, and vigorous activity (55). For participants who did not meet these criteria, OBT in excess of 72 minutes was evaluated using the PARs (Figure 1). If the OBT included activities for which a MET from the 2011 Compendium of Physical Activities (1) could be clearly assigned (e.g. water aerobics: MET = 5.5, code 18355; personal care: 2.0 MET, code 13040; or sleep: 0.95 MET, code 07030), time spent in these activities was added to the overall excel output (n=26), thereby reducing
OBT to less than 72 minutes per day and yielding a valid day. Naps were identified as time asleep outside of 10pm to 7am and occurred greater than two hours before/after nighttime sleep.

Data from the SWA was used to assess adherence to several PA recommendations. This was done in two ways to account for various interpretations of the 2008 Department of Health and Human Services (DHHS) prenatal PA recommendations: 1) ≥ 150 minutes per week accumulated MVPA and 2) ≥ 150 minutes MVPA per week completed in at least 10-minute bouts (57). The American College of Obstetrics and Gynecologists (ACOG) recommends at least 30 minutes of exercise on most (defined as 5 days), if not all days of the week (2) and thus was also used as a comparative standard. A 10-minute bout consisted of at least 8 minutes in MVPA within 10-consecutive minutes thereby allowing for up to 2 minutes below the moderate intensity threshold as previously reported (23,61). Bouts of at least 30-minutes were also assessed with respect to the rule that no more than 2 minutes were below the moderate intensity threshold within a 10-minute period.

**activPAL™ Monitor**

The activPAL™ (PAL Technologies, Ltd, Glasgow, Scotland) is an accelerometer-based posture and activity monitor worn on the right leg over the quadriceps muscle, that has been validated to quantify postural allocation (15) and steps (15,29,42). If the adhesive pad used to attach the AP did not adequately hold the monitor in place, the woman was provided with a roll of surgical tape to use in addition to the adhesive pad. AP outputs were matched to analyze the same valid days used to assess SWA data (see Figure 1). Further, 15-second epochs were analyzed according to previously published methodology (15) which evaluated
average hours per day spent sedentary and upright as well as the number and duration of
sedentary and upright bouts. A bout consisted of any period of time greater than one second
during which a posture was maintained. SB reported by the AP included sleep (nighttime
sleep plus naps) as this monitor is not able to discern between wake time and sleep when
lying down. The key feature regarding this monitor that differs from the SWA is that the AP
can discern between time spent lying down/sitting versus standing or walking. Therefore, the
AP identifies SB based on posture alone, whereas the SWA defines SB as any activity that is
≤ 1.5 METs, regardless of posture. Thus, total SB quantified from each monitor may be
different since it is possible to be in a sedentary posture while engaging in an activity of light
intensity (1.6-2.9 METs).

**Physical Activity Record**

Participants were instructed to record all of their daily activities during the same
seven consecutive days they wore the activity monitors. The purpose of the PAR was to
provide descriptive information that was not provided by the objective activity monitors
regarding the types of activities that were conducted throughout each data collection period.
Specifically, this record was used to assist in the interpretation of the OBT.

**Statistics and Analytical Plan**

The Shapiro-Wilk test for normality revealed the majority of the PA data was not
normally distributed; however the difference of the variables between data collection periods
was primarily normally distributed. Therefore values were reported in medians and the 25th
to the 75th interquartile range (IQR) and paired t-tests were used to determine significant
differences between the first (week 18) and second data collection period (week 35).
Descriptive statistics were conducted on daily totals of steps, minutes spent in sedentary,
light, moderate, and vigorous activity, time spent lying/sitting, standing, and total time spent
sleeping. Significance was set at \( P < 0.05 \). Statistics were run using NCSS 2007 (version
07.1.20, NCSS, LLC., Kaysville, Utah.).

**Results**

**Participant Characteristics**

Participants were on average 29.0 ± 3.5 years old, predominantly married (93%) and
Caucasian (93%), all had some college education, and 54% were nulliparous. Participants
had an average pre-pregnancy body mass index (BMI) of 24.9 ± 5.0 kg/m\(^2\) (underweight
BMI: \( n=1 \); normal: \( n=30 \); overweight: \( n=9 \); obese: \( n=6 \)).

**SenseWear® Armband– Energy Expenditure, Sleep and Activity Profile**

Percentages of a day spent in nighttime sleep, sedentary (includes time spent
napping), light PA, moderate PA, vigorous PA, and OBT at week 18 and 35 are depicted in
Figures 2a and 2b, respectively. With an increase in sedentary time at week 35, a decrease in
light and vigorous PA was observed (\( P < 0.05 \)) even though accumulated and bouts of at least
10 minutes of MVPA per day did not significantly decrease. Total MET-minutes per day
(difference between week 18 and 35 = -110 MET-minutes, \( P < 0.0005 \)) and MVPA MET-
minutes (difference between week 18 and 35 = -20 MET-minutes, \( P < 0.05 \)) in at least a 10-
minute bout per day also significantly decreased from week 18 to 35. Although activity
decreased, energy expenditure increased across pregnancy (\( P < 0.0001 \)). Thirty-nine percent
(n=18) of participants at week 18, and 37% (n=17) at week 35 slept on average between 7-9 hours per night. Although, none of the participants slept less than 5 hours or greater than 9 hours at either time point, 61% and 63% slept less than 7 hours per night at week 18 and 35, respectively. Time (hours) spent sleeping at night did not significantly change, but sedentary time (hours) (including napping) showed a trend increasing from week 18 to week 35 ($P = 0.06$) (Table 1).

**activPAL™**

Although total sedentary and upright time was not significantly different at week 35 compared to week 18, total stepping time and total steps per day significantly decreased ($P < 0.00005$ and $P < 0.0005$) at week 35 (Table 2). The length of sedentary and upright bouts decreased from week 18 to 35 ($P < 0.005$). In addition, the number of transitions between sitting/lying down and standing/stepping, the number of sedentary bouts, and the number of upright bouts per day significantly increased across pregnancy ($P < 0.0005$).

**Adherence to Physical Activity Guidelines**

According to the 2008 DHHS prenatal PA recommendations of accumulated moderate PA, 65% and 61% of women met the guideline at week 18 and 35, respectively. Using the 2008 DHHS PA recommendations for non-pregnant adults which reflect MVPA in a bout of at least 10 minutes, 46% and 28% of women met the guideline at week 18 and 35, respectively. Those who met the guideline spent a median of 235 (193-372) minutes in at least 10-minute bouts of MVPA per week. Three women did not have any bouts of MVPA sustained for at least 10 minutes. According to the ACOG criteria of exercise completed in
bouts of at least 30 minutes of MVPA most days of the week, 17% of women at week 18 and 11% of women at week 35 met the recommendation. Participants completed a median of 2 (0-3) and 0 (0-3) bouts of MVPA which lasted at least 30 minutes at week 18 and 35, respectively. Of those women who completed at least one 30-minute bout of MVPA, the median length of each bout was 91.0 (70.5-166.5) minutes at week 18 and 78.5 (44.8-112.5) minutes at week 35.

**Discussion**

The current study demonstrates that pregnant women spend more than half of their total day and approximately 75% of their time awake in sedentary behaviors regardless of meeting current 2008 DHHS prenatal PA recommendations. Although research has targeted prenatal PA as a means to minimize adverse prenatal outcomes, little attention has been given to behaviors during the rest of the day. The current study demonstrates that SB may be a crucial component of daily behavior that could be modified to achieve optimal pregnancy outcomes. The excessive amount of SB during pregnancy is of great concern as an increase in SB has been recognized as a health hazard in non-pregnant adults (20,30,32-33,43,64). Although it has been previously reported that PA decreases in the 3rd trimester (3,17,53), the current study demonstrates this change is largely due to a decrease in light PA. Moderate PA, which is reflected in adherence to PA recommendations, did not significantly decrease across pregnancy. Although these findings conflict with current reports that demonstrate a decrease in moderate PA across pregnancy (17), the high sensitivity of the SWA allows for a very detailed objective assessment. The reduction in overall activity across pregnancy is evident through a decrease in steps per day and is likely due to a decrease in light PA since
moderate PA did not significantly decrease. Furthermore, the decline in light PA is explained by a trend towards an increase in sedentary behavior. Therefore, the change in activity patterns from light PA to SB may be more relevant when assessing the effect of PA on maternal and fetal health outcomes.

The increase in energy expenditure observed during the 3rd trimester in this study is supported by the literature and is explained by weight gain and increased metabolic demands required for proper fetal growth (5,21,24,39) and development (6). However, the natural rise in metabolism may not be adequate to compensate for the decrease in overall activity and the trend for increased time in SB. Higher levels of total daily activity has been associated with the prevention of excess GWG such that women with > 8.5 MET-hours per week were less likely to gain excessive weight (8). The report of activity in MET-hours or MET-minutes provides a description of the volume of daily activity as it encompasses sedentary, light, moderate, and vigorous PA. In the current study, a significant decrease in average MET-minutes per day from second to third trimester represents an overall reduction in activity.

Since moderate PA does not significantly change across pregnancy, future efforts to prevent prenatal complications should aim to increase overall activity with an emphasis on light PA or NEAT rather than volitional exercise. A previous report from Gradmark et al. emphasizes this need since total activity, rather than subcomponents of PA, were determined to be most strongly associated with insulin sensitivity during pregnancy (26). However, light PA may need to be specifically considered as it has been shown to be a significant contributor to total daily energy expenditure and body weight regulation in non-pregnant adults (41).

A novel feature of the current study is the use of multiple consecutive 24-hour monitoring periods as only one study has previously evaluated PA during pregnancy over an
entire day, yet does not report behaviors as a portion of the entire day (26). Most studies of
PA behavior during pregnancy report monitored time only from when participants woke up
until they went to bed (18,36). This method may not allow for an accurate depiction of
behavior as there is no indication that the monitors were put back on immediately upon rising
in the morning. The delay in putting on the monitor in the morning would result in a
misclassification for sleep rather than capturing activity during that time. The ability of the
SWA to detect OBT strengthens the data in the present study as an accurate and alarming
exemplification of sedentary, light, and moderate-vigorous PA behavior during the second
and third trimester.

Additionally, the 24-hour monitoring period was particularly valuable to capture and
account for nighttime sleep, independent of daytime SB. Nighttime sleep should be assessed
when considering optimal behaviors during pregnancy as disrupted sleep patterns have been
reported to start in the first trimester and continue throughout pregnancy (31,40). Sleep has
been reported to be of poor quality, decreased duration, decreased efficiency, and more
fragmented towards the end of pregnancy (31,45). In addition, hormonal changes during
pregnancy and the growth of the fetus may also lead to difficulty falling asleep (40).
Borodulin and colleagues used a measure of self-report to determine that 61.3% of women
(n=1259) during their second trimester were sleeping between 7-9 hours per night, the
recommended amount for adults (3). Comparatively, in the current study using an objective
assessment of sleep only 39% and 37% of participants meet these recommendations during
the 2nd and 3rd trimester, respectively. Sleep duration and efficiency is of particular concern
during the third trimester in which sleep deprivation (< 5 hours per night) could increase the
risk for preterm and still birth (44,58). Tsai et al. also suggested that daytime napping does
not fully compensate for inadequate nighttime sleep (60) which may increase the risk for nighttime sleep deprivation during pregnancy and increase the risk for hyperglycemia (35). Given the maternal and fetal health concerns associated with inadequate sleep, it is important to assess behavior over a 24-hour period so that sleep and daytime PA can be evaluated in relation to health outcomes.

To date, there is only one other study to have monitored PA and SB in pregnant women over a 24-hour period, allowing for the potential to assess sleep (26). Using the Actiheart, Gradmark et al. determined that women spent 55.5% of their observed time in SB, but it is unclear which behaviors and over what duration this percentage represents since activity is reported as a percentage of wear time (26). Additionally, nighttime sleep was not individually addressed nor specified as part of total SB. Freedson and John have recently referred to the importance of objectively measuring PA over 24 hours as it allows sleep duration to be assessed (22). In addition, the impact of accounting for sleep as a portion of SB was seen in the current study through the comparison of SB as measured by the AP versus SB as measured by the SWA. The AP, which reports time spent in sedentary postures (lying and sitting), revealed participants to be sedentary approximately 76% of the 24 hours which includes nighttime sleep during both the 2nd and 3rd trimester. Separately, SWA is able to distinguish between sleep and awake-sedentary behaviors, thus while 56% of the 24 hours is sedentary, 75% of the time awake is spent in SB. This illustrates the importance of capturing all activity across 24-hour monitoring periods. Furthermore, it is important to identify daytime SB including naps separately from nighttime sleep as daytime SB appears to be a promising modifiable lifestyle factor.
The strengths of this study design and analysis include the use of consecutive 24-hour monitoring periods, measurement of sleep duration as a component of daily behavior, and the use of objective (AP, SWA) forms of PA assessment. To our knowledge, this is also the first study to evaluate SB during pregnancy using the AP. In addition, most participants exhibited excellent compliance demonstrated by minimal OBT, allowing for complete data sets for analysis.

One limitation to the current study is that a maximum of six full days of data were used for analysis and were compared to weekly PA recommendations. Although only four days of data were deemed necessary to represent habitual activity (55), 91% of women at week 18 and 87% of women at week 35 had 6 days of valid data. The remaining 9% of participants at week 18 had five days of data and the other 13% of participants at week 35 was evenly split with 5- and 4-days of valid data. Comparatively, other studies have reported activity during pregnancy with respect to PA recommendations using less data from subjective questionnaires (3,17,19), retrospective databases (17,28), a smaller monitoring period of four days (36) or 72-hours (53), or decreased compliance (18,52-53). Thus, while the use of six days of data in the current study may not be ideal to assess weekly activity, the high compliance of participants in combination with objective monitoring provides a more comprehensive view of prenatal PA than what has been previously reported.

The inconsistency in lengths of monitoring periods further complicates the interpretation of adherence to prenatal PA guidelines since multiple guidelines can be applied to assess prevalence. In the current study, 65% and 61% of participants adhered to the 2008 DHHS prenatal PA guideline (≥ 150 minutes of accumulated MVPA), whereas 17% and 11% of participants adhered to the ACOG recommendation (≥ 30 minutes MVPA most days
of the week completed in bouts of at least 30 minutes) during the 2nd and 3rd trimester, respectively. Therefore, the differing lengths of monitoring periods in addition to the application of various prenatal PA guidelines makes it difficult to assess the implications of activity during pregnancy.

This study demonstrates that after accounting for nighttime sleep, pregnant women spend more than half of the day (24 hours) or 75% of time awake in sedentary behaviors. However, according to the DHHS guidelines, most women are also simultaneously meeting prenatal PA recommendations. SB remained the most predominant behavior across pregnancy, but light PA, vigorous PA, total steps per day, and total time spent stepping per day significantly decreased in the 3rd trimester. The use of MET-minutes per day to describe total daily activity (sedentary, light, moderate, vigorous) over 24-hours allows activities of all intensities to be recognized. This singular measurement provides a broad picture of behavior and is advantageous to use with the evaluation of activity and prenatal outcomes. In addition to increasing moderate PA, more attention should be given to increasing overall movement, of any intensity, during pregnancy. Attention to maintaining an active lifestyle during pregnancy has focused on increasing MVPA; however, promotion of light and moderate activity beyond volitional exercise may be an additional strategy that should be tested in future interventions to prevent adverse maternal and fetal health outcomes.
References


reduced excessive gestational weight gain in pregnant women under a randomised controlled trial. *BJOG.* 2012;119(1):70-7.


### Table 1 - Energy expenditure, sedentary behavior, and physical activity during the 2nd and 3rd trimester (n=45)

<table>
<thead>
<tr>
<th>SenseWear® Armband</th>
<th>Week 18&lt;sup&gt;a&lt;/sup&gt;</th>
<th>Week 35&lt;sup&gt;a&lt;/sup&gt;</th>
<th>Week 35-Week 18&lt;sup&gt;a&lt;/sup&gt;</th>
<th>T-Value&lt;sup&gt;b&lt;/sup&gt; or Z-Value&lt;sup&gt;c&lt;/sup&gt;</th>
<th>P-Value&lt;sup&gt;d&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy Expenditure (kcal·d&lt;sup&gt;-1&lt;/sup&gt;)</td>
<td>2076 (1939-2177)</td>
<td>2245 (2078-2479)</td>
<td>140 (39-283)</td>
<td>4.31&lt;sup&gt;c&lt;/sup&gt;</td>
<td>0.000016&lt;sup&gt;c&lt;/sup&gt;</td>
</tr>
<tr>
<td>Nighttime Sleep (hrs·d&lt;sup&gt;-1&lt;/sup&gt;)</td>
<td>6.8 (6.2-7.3)</td>
<td>6.7 (6.3-7.2)</td>
<td>-0.2 (-0.7-0.4)</td>
<td>-0.53&lt;sup&gt;b&lt;/sup&gt;</td>
<td>0.60&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>Naps (min·d&lt;sup&gt;-1&lt;/sup&gt;)</td>
<td>9 (0-20)</td>
<td>10 (3-22)</td>
<td>3 (-8-11)</td>
<td>0.44&lt;sup&gt;b&lt;/sup&gt;</td>
<td>0.66&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>All Sleep (hrs·d&lt;sup&gt;-1&lt;/sup&gt;)</td>
<td>7.1 (6.3-7.5)</td>
<td>7.0 (6.5-7.5)</td>
<td>-0.1 (-0.6-0.4)</td>
<td>-0.67&lt;sup&gt;b&lt;/sup&gt;</td>
<td>0.51&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>Sedentary (excludes nighttime sleep, includes naps) (hrs·d&lt;sup&gt;-1&lt;/sup&gt;)</td>
<td>12.7 (12.1-13.6)</td>
<td>13.7 (11.3-14.7)</td>
<td>0.5 (-0.5-1.4)</td>
<td>1.93&lt;sup&gt;b&lt;/sup&gt;</td>
<td>0.060&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>Light PA (hrs·d&lt;sup&gt;-1&lt;/sup&gt;)</td>
<td>2.9 (2.1-4.1)</td>
<td>2.3 (1.5-3.8)</td>
<td>-0.4 (-1.1-0.12)</td>
<td>-2.01&lt;sup&gt;b&lt;/sup&gt;</td>
<td>0.050&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>Accumulated Moderate PA (min·d&lt;sup&gt;-1&lt;/sup&gt;)</td>
<td>37 (19-61)</td>
<td>31 (15-60)</td>
<td>-7 (-17-12)</td>
<td>-1.15&lt;sup&gt;c&lt;/sup&gt;</td>
<td>0.25&lt;sup&gt;c&lt;/sup&gt;</td>
</tr>
<tr>
<td>Accumulated Vigorous PA (min·d&lt;sup&gt;-1&lt;/sup&gt;)</td>
<td>0.8 (0-6)</td>
<td>0 (0-1)</td>
<td>-0.3 (-5-0)</td>
<td>-3.06&lt;sup&gt;c&lt;/sup&gt;</td>
<td>0.0022&lt;sup&gt;c&lt;/sup&gt;</td>
</tr>
<tr>
<td>Moderate PA in ≥ 10 minute bouts (min·d&lt;sup&gt;-1&lt;/sup&gt;)</td>
<td>23 (7-38)</td>
<td>17 (3-34)</td>
<td>-3 (-19-2)</td>
<td>-1.70&lt;sup&gt;b&lt;/sup&gt;</td>
<td>0.095&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>MET minutes in ≥ 10 minute bouts (min·d&lt;sup&gt;-1&lt;/sup&gt;)</td>
<td>121 (26-167)</td>
<td>66 (11-139)</td>
<td>-39 (-89-6)</td>
<td>-2.51&lt;sup&gt;b&lt;/sup&gt;</td>
<td>0.016&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>Total MET-minutes (·d&lt;sup&gt;-1&lt;/sup&gt;)</td>
<td>1826 (1715-1942)</td>
<td>1710 (1590-1880)</td>
<td>-110 (-184-4)</td>
<td>-4.12&lt;sup&gt;b&lt;/sup&gt;</td>
<td>0.00016&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
</tbody>
</table>

<sup>a</sup>Values reported in median (25th-75th percentile); <sup>b</sup>Statistic from paired t-test; <sup>c</sup>Statistic from Wilcoxon rank-sum test; PA = Physical activity
Table 2 - Daily activity profile including sedentary and upright time during the 2nd and 3rd trimester (n=45)

<table>
<thead>
<tr>
<th>activPAL™</th>
<th>Gestation Length (weeks)</th>
<th></th>
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</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Week 18&lt;sup&gt;a&lt;/sup&gt;</td>
<td>Week 35&lt;sup&gt;a&lt;/sup&gt;</td>
<td>P-Value</td>
</tr>
<tr>
<td>Sedentary</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sedentary time (includes all sleep) (hrs·d&lt;sup&gt;-1&lt;/sup&gt;)</td>
<td>18.2 (17.1-19.0)</td>
<td>18.3 (17.6-19.4)</td>
<td>0.33&lt;sup&gt;a&lt;/sup&gt;</td>
<td></td>
</tr>
<tr>
<td>Sedentary (%) of day</td>
<td>76 (71-79)</td>
<td>76 (73-81)</td>
<td></td>
<td>0.33&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>Number of Sedentary Bouts (number·d&lt;sup&gt;-1&lt;/sup&gt;)&lt;sup&gt;b&lt;/sup&gt;</td>
<td>35 (25-44)</td>
<td>46 (30-59)</td>
<td></td>
<td>0.0032&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>Length of Sedentary Bout (min·d&lt;sup&gt;-1&lt;/sup&gt;)&lt;sup&gt;b&lt;/sup&gt;</td>
<td>32 (24-42)</td>
<td>22 (18-37)</td>
<td></td>
<td>0.00053&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>Number of Transitions Between Sedentary (sit/lay) to Upright (·d&lt;sup&gt;-1&lt;/sup&gt;)&lt;sup&gt;c&lt;/sup&gt;</td>
<td>35 (25-45)</td>
<td>48 (31-65)</td>
<td></td>
<td>0.0021&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>Upright</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Upright time (includes stepping &amp; standing time) (hrs·d&lt;sup&gt;-1&lt;/sup&gt;)</td>
<td>5.8 (5.0-6.9)</td>
<td>5.7 (4.6-6.4)</td>
<td>0.33&lt;sup&gt;a&lt;/sup&gt;</td>
<td></td>
</tr>
<tr>
<td>Stepping time (hrs·d&lt;sup&gt;-1&lt;/sup&gt;)&lt;sup&gt;d&lt;/sup&gt;</td>
<td>3.5 (2.4-4.5)</td>
<td>2.1 (1.4-3.4)</td>
<td></td>
<td>0.000019&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>Standing time (hrs·d&lt;sup&gt;-1&lt;/sup&gt;)&lt;sup&gt;c&lt;/sup&gt;</td>
<td>2.1 (1.6-2.9)</td>
<td>3.3 (1.9-4.6)</td>
<td></td>
<td>0.00044&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>Upright (%) of day</td>
<td>24 (21-29)</td>
<td>24 (19-27)</td>
<td></td>
<td>0.33&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>Number of Upright Bouts (·d&lt;sup&gt;-1&lt;/sup&gt;)&lt;sup&gt;c&lt;/sup&gt;</td>
<td>34 (25-45)</td>
<td>44 (30-59)</td>
<td></td>
<td>0.0030&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>Length of Upright Bout (min·d&lt;sup&gt;-1&lt;/sup&gt;)&lt;sup&gt;b&lt;/sup&gt;</td>
<td>10 (7-14)</td>
<td>7 (6-12)</td>
<td></td>
<td>0.000092&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>Steps</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Steps (number·d&lt;sup&gt;-1&lt;/sup&gt;)&lt;sup&gt;c&lt;/sup&gt;</td>
<td>10,102 (7329-12,408)</td>
<td>7323 (6187-10,151)</td>
<td></td>
<td>0.00016&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
</tbody>
</table>

<sup>a</sup>Values reported in median (25<sup>th</sup>-75<sup>th</sup> percentile); <sup>b</sup>Statistic from paired t-test; <sup>c</sup>Statistic from Wilcoxon rank-sum test
Figures

Figure 1 - Number of participants included in the analysis of each physical activity monitor based on criteria for valid data
OBT = off-body time

Complete Data Sets: n=48

Physical Activity Analysis

Wk 18 n=48

Eliminated from ALL monitor analysis for General Incompliance: n=2

SWA: valid data (<72 min OBT for >4d) n=46

Participants with Valid data: n=46
# of Valid Days:
4d: n=0
5d: n=4
6d: n=42
Participants with Invalid data: n=0

ActivPAL (follows valid SWA days) n=46

Participants with Valid data: n=43
# of Valid Days:
4d: n=3
5d: n=3
6d: n=37
Participants with Invalid data: n=3
Participants with no file: n=3

Wk 35 n=48

Eliminated from ALL monitor analysis for General Incompliance: n=2

SWA: valid data (<72 min OBT for >4d) n=46

Participants with Valid data: n=46
# of Valid Days:
4d: n=3
5d: n=3
6d: n=40
Participants with Invalid data: n=0
Participants with no file: n=3

ActivPAL (follows valid SWA days) n=46

Participants with Valid data: n=43
# of Valid Days:
4d: n=3
5d: n=3
6d: n=37
<table>
<thead>
<tr>
<th>Activity</th>
<th>2nd Trimester (Week 18)</th>
<th>3rd Trimester (Week 35)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nighttime Sleep</td>
<td>29%</td>
<td>29%</td>
</tr>
<tr>
<td>Sedentary (includes Naps)</td>
<td>53%</td>
<td>55%</td>
</tr>
<tr>
<td>Light PA*</td>
<td>13%</td>
<td>11%</td>
</tr>
<tr>
<td>Moderate PA</td>
<td>3%</td>
<td>3%</td>
</tr>
<tr>
<td>Vigorous PA*</td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td>OBT</td>
<td>2%</td>
<td>2%</td>
</tr>
</tbody>
</table>

*P < 0.05
CHAPTER 4. CARBOHYDRATE INTAKE AND TOTAL DAILY PHYSICAL ACTIVITY PREDICT GESTATIONAL WEIGHT GAIN IN LATE PREGNANCY

A paper to be submitted to The American Journal of Clinical Nutrition

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Abstract

BACKGROUND: Previous efforts to prevent excessive gestational weight gain (GWG) have focused on promoting moderate physical activity (PA) and/or controlling dietary intake. To determine a dietary and activity profile needed to achieve appropriate weight gain, lifestyle should be assessed with regard to total activity and diet quality.

OBJECTIVE: The primary purpose of this study was to identify modifiable aspects of total PA (sedentary, light, moderate, and vigorous), and dietary intake to predict GWG.

DESIGN: During week 18 ± 1 week and week 35 ± 1 week, 46 pregnant women wore 2 validated PA monitors (activPAL™ and SenseWear® Mini Armband) 24 hours per day for 7 consecutive days. The monitors provided estimates of time spent in all intensities of activity (sedentary, light, moderate, and vigorous), total sleep duration, steps, and total activity in MET-minutes per day. Naps were separated from nighttime sleep and included as sedentary behavior. A weighed 3-day diet record was used to assess total energy intake, macronutrient intake, and diet quality using the Healthy Eating Index (HEI) at each time point. GWG was determined using self-reported pre-pregnancy weight and the measured weight at each data collection period after adjustment to reflect weight gain at exactly week 18 and 35. Differences in PA subcomponents between the ²nd and ³rd trimester were determined with
paired t-tests and values were reported in medians (25\textsuperscript{th}-75\textsuperscript{th} percentile). Multiple and stepwise regression (n=42) were used to develop prediction models for GWG at week 18 and 35. **RESULTS:** Across all pre-pregnancy BMIs, 35% and 46% gained in excess of the 2009 IOM guidelines by week 18 and 35, respectively. All subcomponents of activity except vigorous PA did not significantly change, yet all measures of total activity including total MET-minutes (min·d\textsuperscript{-1}) (P < 0.05), MET-minutes in ≥ 10 min bouts (min·d\textsuperscript{-1}) (P < 0.05), and steps per day (P < 0.0005) significantly decreased from week 18 to 35. Total energy intake was the only dietary variable which significantly increased across pregnancy (P < 0.05). Total MET-minutes (min·d\textsuperscript{-1}) (P = 0.0376) and protein intake (g·d\textsuperscript{-1}) (P = 0.071), after accounting for naps, were the best predictors of GWG at week 18. Total MET-minutes (min·d\textsuperscript{-1}) (P = 0.038) remained significant at week 35, but carbohydrate (CHO) intake (g·d\textsuperscript{-1}) (P = 0.098) was the best dietary predictor of GWG at week 35. **CONCLUSION:** This study demonstrates various lifestyles can lead to appropriate GWG based on PA levels and dietary intake. The prediction models from this study provide a basis for the development of individualized diet and activity prescription to achieve appropriate GWG. Further research is needed to address the quality of CHOs with respect to GWG.

**Introduction**

Excessive gestational weight gain (GWG) affects nearly half of all pregnancies in the United States and is associated with adverse maternal and fetal outcomes such as, but not limited to, increased risk of gestational diabetes mellitus (1), preeclampsia (2-5), large for gestational age infants (2,6), childhood obesity (7), and post-partum weight retention (8). Although the Institute of Medicine released updated recommendations for appropriate GWG
in 2009, many pregnant women and medical providers are left with the question of what constitutes the appropriate lifestyle choices needed to achieve the recommended amount of weight gain.

Potential lifestyle strategies including nutrition and/or exercise to prevent excessive GWG have been evaluated (9-14). Mottola et al. found that a combination of caloric restriction, limiting carbohydrate intake, and a partially supervised walking program successfully prevented excessive GWG in 80% of participants (10). Other interventions have addressed GWG in response to a low- and-moderate-intensity partially monitored walking program (11); counseling on diet, physical activity (PA), and GWG recommendations (12); face-to-face prenatal diet counseling versus the distribution of brochures (13); and a low-glycemic diet compared to a low-fat diet (14). Although the aforementioned interventions are diverse in methodology, collectively these studies demonstrate that altering lifestyle choices may prevent excess GWG according to the IOM categories based on pre-pregnancy body mass index (BMI).

Previous PA interventions to prevent excess GWG focused on promoting moderate-vigorous (MV) PA rather than reducing sedentary behavior (SB) or increasing light activity, which represents a larger portion of daily behavior. To date, no interventions have been conducted to specifically reduce SB independent of increasing volitional exercise during pregnancy, thus the direct relationship between time spent in SB and GWG is unknown. In addition, the role of non-exercise activity thermogenesis (NEAT) or energy expended from activities of daily living exclusive of volitional exercise, has not been identified during pregnancy. This concept suggests that all activity such as occupational, domestic, or leisure activity, in addition to intentional moderately-intense exercise may influence weight gain.
Cohen et al has further demonstrated this by reporting an association between total activity measured in metabolic equivalent of task hours (MET-hours) per week and adherence to GWG recommendations (15).

Dietary intervention has been documented as an effective strategy to reduce excessive GWG (16-17) and may have a greater impact than just altering PA or both diet and PA (16). Since various methods have been used to evaluate diet including quantitative assessment of macro- and micronutrient intake including 24-hour recalls (18), 1- (10-11), 3- (19), or 7-day (13) diet records, and intake of singular food groups (13,20), it is difficult to draw conclusions on the composition of the optimal diet needed to create a diet prescription to prevent excessive gestational weight gain.

It is important to address the quality of calories consumed during pregnancy such that the possible relationship with GWG may be determined. The assessment of diet quality during pregnancy may be achieved through the use of the Healthy Eating Index which has been validated in the non-pregnant population, but is also appropriate for pregnancy. The USDA Food Patterns meet the prenatal IOM nutrient recommendations, and with the assessment of diet quality based on intake per calorie, the increase in both macro- and micro-nutrients during pregnancy will be appropriately reflected as a portion of total intake (21).

The ideal dietary and PA profile needed to achieve appropriate weight gain per the IOM GWG recommendation has not been identified. To evaluate the relationship between lifestyle choices and GWG, time spent in PA of all intensities in addition to physical inactivity and dietary intake including dietary quality should be assessed as potential determinants of GWG. By considering all aspects of daily behavior, a broad perspective of the effects of lifestyle on GWG may be established. Therefore, the primary purpose of this
prospective, longitudinal study was to identify modifiable aspects of total PA including sedentary, light, moderate, and vigorous activity, and dietary intake to predict GWG.

**Methods**

**Participants**

Various forms of announcements such as advertisements and campus-wide emails were used to recruit healthy pregnant women from local obstetric clinics. Fifty-six women, pregnant prior to 19 weeks gestation, 18-45 years of age, with a singleton pregnancy were enrolled in the observational study. Women who smoked during pregnancy or had a history of chronic disease were excluded. Eight women did not complete the study due to time constraints (n=6), skin irritation (n=1), and pre-term delivery (n=1). In addition, two women had insufficient wear time (see *SenseWear® Activity Monitor*) and were excluded from the PA and diet analysis at both study time points. Thus, 46 complete data sets were assessed for adherence to data collection procedures (*Figure 1*).

**Study Design**

Data collection occurred at week 18 ± 1 (“week 18”) and week 35 ± 1 (“week 35”) of gestation. Each participant collected data for seven consecutive days during each data collection period. No advice was provided during the study regarding prenatal nutrition or exercise. During the enrollment visit that occurred at week 18, each participant’s height (Ayrton 226 Hite-Rite Precision Mechanical Stadiometer, quick Medical GS, Snoqualmie, WA) and weight (Detecto Model 6855 Cardinal Scale, Manufacturing Co., Webb City, MO) were measured and recorded to the nearest 0.1 cm and 0.1 kg, respectively. Participants
completed a medical history questionnaire, and signed documents allowing for communication with their medical provider regarding study qualification criteria. Instructions for how to wear two activity monitors (SenseWear® Mini armband (SWA), and activPAL™ (AP)) were discussed with each participant verbally and a written copy was additionally sent home. In addition, the participant was given instructions on recording dietary intake. During the second data collection period, the participant’s weight measurement and all instructions on how to collect PA and dietary intake data were repeated.

**Physical Activity Assessment**

Each participant was instructed to wear two PA monitors for 7 days, 24 hours a day except when showering or swimming. The SenseWear® armband (BodyMedia, Pittsburgh, PA) was worn on the left arm over the triceps and provided data on energy expenditure (EE) (kcals/d) and time spent in the following behaviors: nighttime sleep, napping, and sedentary, light, moderate, and vigorous PA. Total metabolic equivalent of task (MET) minutes and MET-minutes of MVPA in bouts of at least 10 minutes were a determined to reflect total activity. Estimates of EE between the SWA and indirect calorimetry have previously been reported at mid-pregnancy using algorithm 5.2e (22). The activPAL™ (PAL Technologies, Ltd, Glasgow, Scotland) is an accelerometer-based posture and activity monitor worn over the right quadriceps muscle. This monitor provides an estimate of steps per day (23-25) and has been validated to quantify postural allocation (26). AP outputs were matched to the same days used to assess SWA data (Figure 1). The data analysis was standardized to represent 6, 24-hour periods beginning and ending at midnight on the 1st and 6th day the monitors were
worn. Additional information describing monitor wear-time has been described elsewhere (Chapter 3).

**Assessment of Dietary Intake**

A 3-day weighed diet record was used to provide quantitative information regarding habitual food choices. Participants were instructed to weigh and record all food and beverage consumption and use of supplements during two weekdays and one weekend day (not required to be consecutive) that coincided with the timeframe during which the PA monitors were worn.

Diet records were analyzed for total energy, macro- and micronutrient content, and food groups using NutritionistPro™ Diet Analysis (Axxya Systems, Stafford, Texas). Average intake of fruit, whole fruit, vegetables, dark green and orange vegetables and legumes, grains, whole grains (evaluated using Nutrition Data System for Research (NDSR), University of Minnesota), milk, meat and beans, oils, saturated fat, and sodium were used to determine dietary quality using the Healthy Eating Index (HEI) 2005. Using a previously reported method (27-29), under-reporters were defined as participants with a ratio of energy expenditure (SWA) to reported energy intake as greater than 1.2 (Figure 1).

**Gestational weight gain**

Gestational weight gain (GWG) was determined using the 2009 Institute of Medicine (IOM) weight gain guidelines. Total and weekly GWG recommendations based on pre-pregnancy BMI were as follows: underweight: 28-40 lbs (1-1.3 lbs/week); normal weight: 25-35 lbs (0.8-1 lbs/week); overweight: 15-25 lbs (0.5-0.7 lbs/week); and obese: 11-20 lbs
GWG at week 35 was used as a proxy for total GWG. Weight taken during the 2nd data collection period (between weeks 34-36 of gestation) was standardized such that all values reflect weight at week 35 to control for data collected at varying gestational ages among participants (i.e. collection at week 34 versus week 36 of gestation). This was accomplished by subtracting the recommended amount of weight gain per day for each day of gestation greater than 35 weeks OR adding the recommended amount of weight gain per day for each day under 35 weeks. Self-reported pre-pregnancy weight was then subtracted from this standardized week 35 weight to provide an indication of total weight gain. GWG at week 18 was determined similarly.

Statistical Analyses

The data analysis was conducted in two parts. In the first stage, NCSS 2007 (version 07.1.20, NCSS, LLC., Kaysville, Utah.) was used to conduct descriptive and inferential statistics on behavioral variables (daily nighttime sleep, minutes in naps, steps, total MET-minutes, minutes of MVPA in at least 10-minute bouts, MET-minutes of MVPA in at least 10-minute bouts, total time in sedentary behavior, and total time spent in light, moderate, and vigorous PA) and dietary variables (all components of HEI, HEI score, and intake of energy, carbohydrates, protein, and total fat). Further paired t-tests and Wilcoxon rank-sum tests were used to determine differences between variables at the first (week 18) and second data collection period (week 35). The level of significance was set at $P < 0.05$.

In the second part of the data analysis, daily averages were calculated for each of the explanatory variables rather than totals for each individual’s monitoring period, e.g. average number of steps per day, average number of minutes in moderate PA per day, average
number of minutes spent napping per day, average energy intake per day, etc. Further GWG for each individual was adjusted to reflect their estimated GWG for both the first (week 18) and second (week 35) data collection periods. To determine which explanatory variables were most associated with GWG, multiple regression analysis using JMP pro 10 (SAS Institute Inc., Cary, NC, 2012) was conducted separately to predict GWG at week 18 using variables measured at week 18, and to predict GWG at week 35 using variables measured at week 35. In order to determine a good subset of these explanatory variables that were most highly related to the GWG, alternating stepwise regression (P < 0.15) was used and values with the smallest AIC were selected.

Results

Participant Characteristics

Participants were an average of 29.0 ± 3.5 years old, primarily married (93%), Caucasian (93%), and all were college educated (100%). Participants had an average of 0.6 ± 0.8 live children while 54% were nulliparous. Average pre-pregnancy body mass index (BMI) of participants was 24.9 ± 5.0 kg/m2 (underweight BMI: n=1; normal: n=30; overweight: n=9; obese class I: n=3; obese class II: n=3).

Dietary Intake

Nine participants at week 18 and 12 participants at week 35 were identified as under-reporters as described per methods; thus this data was not included in the analysis. Energy intake significantly increased across pregnancy (P < 0.05) (Table 1). No significant changes for protein and total fat intake were observed, but there was a trend for an increased
carbohydrate intake ($P = 0.069$) from week 18 to 35. No significant differences were seen in the components of the HEI or in the total HEI score from the 2nd to 3rd trimester (Table 2). However, 25% of participants at week 18 and 38% at week 35 had a score below 50.

**Gestational Weight Gain**

Across all pre-pregnancy BMIs, 35% and 46% gained in excess of the 2009 IOM guidelines at week 18 and 35, respectively. Only 39% and 37% of participants met guidelines at each time point. At week 18 and 35, excessive GWG was most prevalent in women with an overweight and obese class I pre-pregnancy BMI. Women with a normal pre-pregnancy BMI were most adherent to the guidelines (Table 3). Since all women with an obese class II pre-pregnancy BMI lost weight by week 18 and were identified as outliers, they were removed from regression analyses.

**Prediction of GWG at Week 18 Using Week 18 Variables**

Total MET-minutes per day was the most significant predictor of GWG ($P = 0.038$) at week 18. Additionally, protein intake (g/day) was the dietary variable most predictive of GWG ($P = 0.071$), but only after accounting for time spent napping ($P = 0.083$). Therefore, the best prediction model ($R^2 = 0.29$, root means square error of prediction [rMSEP] = 2.18) for GWG at week 18 was: Predicted week 18 weight gain (kg) = 9.6615311 + (-0.004302*MET-minutes/d) + (0.0343946*Protein Intake (g·d⁻¹)) + (-0.059035*Naps (min·d⁻¹)).
Prediction of GWG at week 35 using week 35 variables

Total MET-minutes per day was the most significant PA variable (P = 0.038) and carbohydrate intake (g/day) was the dietary variable (P = 0.098) most predictive of GWG at week 35. Other dietary variables which were positively, yet not significantly associated with weight gain, included energy intake, total fat intake, and total protein intake. Therefore, the best prediction model ($R^2 = 0.19$, $rMSEP = 3.99$) for GWG at week 35 was: Predicted week 35 weight gain (kg) = $20.700975 + (-0.008357\times\text{MET-minutes}\cdot\text{d}^{-1}) + (0.0213858\times\text{CHO Intake (g}\cdot\text{d}^{-1}))$.

Discussion

The current study demonstrates GWG can be predicted by total daily MET-minutes during both the second and third trimester of pregnancy. Additionally, protein intake (g/day), after accounting for naps (min/day) (Figure 2a), and CHO intake (g/day) (Figure 2b), are positively associated with GWG at week 18 and 35, respectively. Previous interventions have primarily focused on increasing MVPA to prevent excessive GWG (10-11,31). However, the current study suggests that MVPA is only a portion of the activity that contributes to GWG. Total activity may provide a more comprehensive picture of lifestyle during pregnancy and therefore may serve as an important predictor of GWG.

In a systematic review and meta-analysis of 44 randomized control trials, dietary interventions were found to be more effective than just PA or a combination of diet and PA to reduce excessive GWG (16). These studies only evaluated the effects of MVPA, rather than assessing total daily PA, with respect to GWG. Due to the lack of information of total PA during pregnancy, specifically NEAT (32), MET-minutes were assessed to capture all
activity representative of a women’s daily lifestyle including sleep, awake sedentary behaviors, occupational PA, and all other activity categorized as light, moderate or vigorous. The accumulation of activity assessed via total daily MET-minutes, rather than measures of MVPA alone, provides insight on active or inactive lifestyles as PA of all intensities and sleep are encompassed in the measure of MET-minutes.

The significant decrease in total activity (MET-minutes) across pregnancy may explain the change in dietary variables predictive of GWG from second to third trimester. Since CHO and protein intake did not significantly change across pregnancy, the decrease in total PA (3rd trimester) may have accompanied a reduction in CHO oxidation and an increase in protein utilization. Therefore, the decreased use of CHO and increased use of protein in late pregnancy may leave excess CHO substrate available for storage resulting in weight gain. The significance of protein intake as a predictor of GWG at week 18 and not week 35 may be the result of increased protein turnover, or utilization, from second to third trimester since protein intake did not change across pregnancy. During the second trimester, 78% of participants consumed in excess of the RDA of 1.1g/pre-pregnancy body weight (kg) of protein per day with an average of 120 ± 30% of the recommendation among all participants. Excessive intake of protein without an increase in utilization during the second trimester may explain the relationship between increased protein intake and increased GWG at week 18 and not at week 35.

Contrary to the potential increased protein utilization, CHO utilization is likely to decrease during the third trimester, and may explain the positive relationship observed in the current study. CHO oxidation has been reported to decrease across pregnancy in response to decreased cellular uptake of glucose resulting from increased insulin resistance (33-34).
Since total CHO intake is representative of the sum of simple and complex CHO without regard to quality, the relationship of CHO intake and GWG may be a result of a mixed effect between the intake of refined grains and simple sugars rather than from whole grains and complex CHOs. At week 35, 100% of women exceeded the RDA of 175g CHO per day and on average they consumed an excess of 142.0 ± 40.4g of CHO with respect to the RDA. On average, 54% of total energy intake was from CHOs. Although this is in agreement with the Acceptable Macronutrient Density Range of 45-65% of total energy intake from CHO (35), the composition of these CHOs may not be optimal. At week 35, only 19% of women met the recommended whole grain intake per the DGA and an average of 35% of their energy intake came from solid fats and added sugars (SoFAAs), compared to the recommendation of less than 25%. Therefore, the poor quality of CHO intake, regardless of total calories consumed, is a possible explanation for the relationship with GWG.

Several studies demonstrate the importance of the glycemic index with regard to quality of CHOs. Perichart-Perera et al. reports a decreased prevalence of excessive GWG in pregnant women who consumed a low-glycemic index diet compared to those who consumed all types of CHOs (36). Additionally, Knudsen et al. observed higher rates of excessive GWG in the highest quintile of glycemic load (37). Furthermore, Barger describes a relationship between a low-glycemic diet and reduced risks of infertility, preterm birth, and gestational diabetes mellitus (38). Mottola et al. observed reduced rates of excessive GWG through a diet and exercise intervention beginning in the second trimester which involved 2000 kcals per day, 40-55% of total energy intake from complex and low-glycemic CHOs (200-275g), and 30% of total energy from fat (10). Compared to baseline (week 16-20 of gestation), participants significantly decreased their CHO intake from 318.5 ± 155.1g to
259.1 ± 93.9g (10). The findings of the current study may explain why Mottola et al. was successful in reducing excessive GWG using PA and regulation of CHO intake.

Previous prediction models of GWG have identified energy intake (39), change in activity and energy intake relative to pre-pregnancy (40), and pre-pregnancy BMI (18) as predictors of GWG. The prediction models resulting from the current study using total daily PA (MET-minutes/day) with either protein intake (g/day) (week 18, Figure 2a) or CHO intake (g/day) (week 35, Figure 2b) to predict GWG can be applied across BMI categories. These models can be used to predict any amount of weight gain: appropriate, inadequate, or excessive. In effect, there is an inverse relationship between total daily activity and GWG at week 18 and 35. Additionally, there is a direct relationship between protein intake and GWG at week 18 and between CHO intake and GWG at week 35. Figures 2a and 2b, depict isolines for appropriate GWG at week 18 and 35 for each BMI category and demonstrates that adequate weight gain can be achieved as a result of a multitude of behaviors. For example, a woman with a normal pre-pregnancy BMI who wants to gain 24.3 lbs at week 35 (to be on track to gain 30 lbs by 40 weeks) could combine any amount of total daily activity and CHO intake as long as those points, intersect at any point on the isoline of Figure 2b. Figures 2a and 2b exhibit the use of prediction models to predict appropriate GWG; however, a similar graph could be created using the same model to predict either excessive or inadequate GWG. Therefore, these models are useful in identifying the results of various combinations of protein intake (week 18) or CHO intake (week 35) and daily activity on GWG. It is important to acknowledge the daily reference intakes (DRIs) recommend a minimum of 175 g CHO/day to prevent ketosis during pregnancy (35). The respective number of MET-minutes needed to gain adequate weight while consuming 175g of CHO is
1310 MET-minutes for a woman with a normal pre-pregnancy BMI. However, this is less than physiologically possible since a minimum of 1,368 MET-minutes must be achieved per day as that is the amount relative to sleeping (0.95 MET) for 24 hours (0.95 MET·min⁻¹*60 min·d⁻¹*24 hr·d⁻¹ = 1,368 MET-minutes). Therefore, CHOs should be consumed in adequate amounts to prevent ketosis and promote healthy weight gain while considering daily PA.

Using the average number of MET-minutes per day within each BMI category, the amount of CHOs (g/day) required to meet the IOM weight gain guidelines (adjusted to reflect weight at week 35) was determined (Table 4). It is evident that the majority of normal weight women gained appropriate gestational weight on average as they have a positive corresponding CHO intake with response to activity (MET-minutes). The overweight and obese class I women had higher rates of excessive GWG on average given their activity as evidenced by a negative recommended CHO intake (g/day) needed to achieve appropriate weight gain.

A novel aspect of this study was the use of MET-minutes to reflect total daily activity. To our knowledge, there is only one other study which evaluated METs over time with respect to GWG. Cohen et al. observed a reduced risk of excessive GWG with greater than 8.5 MET-hours of total activity (sedentary, light, moderate, vigorous) per week assessed via a subjective questionnaire (15). However, the assessment tool used in the aforementioned study was intended to assess activity across an entire trimester, not daily activity. Comparatively, the current study uses total MET-minutes from all activity across consecutive 24-hour periods. This allows for evaluation of total daily activity, including time spent asleep with respect to GWG. Since previous studies have focused on the association to MVPA, a small portion of the day, rather than addressing behavior over a 24-hour period, this study provides a more expansive insight on the intensity of activities which may
contribute to GWG. Additionally, the use of the HEI to assess dietary quality allows further clarification on the composition of the diet with respect to identifying predictors of excessive GWG. Consequently, this allowed for assessment of the quality of carbohydrate intake.

Lastly, the standardization of GWG at week 18 and 35 allowed for consistent interpretation of the IOM guidelines, also adjusted to reflect recommended weight at week 18 and 35, between participants. Various methods to determine GWG have been previously reported, yet some approaches do not allow for consistent assessment between participants. Previous studies either did not specify which weight was used to determine GWG (1,41), used a measure of self-reported final weight pre-delivery (42), or used weights measured during prenatal visits at various points in gestation which are inconsistent among participants (2). The inconsistency in weights used to determine GWG potentially allows for women to be compared to the same weight gain standards even though their length of gestation during which weight gain was assessed is different.

The current study took a unique approach by evaluating measures of activity, diet composition, and diet quality as potential predictors of GWG. The resulting models to predict GWG at week 18 and 35 of gestation provide preliminary data for an approach that could be incorporated into clinical practice to prevent excessive GWG.

A possible limitation of this study was the use of an average of one week of data collected during each the second and third trimester was used to assess behaviors which predict weight gain over an entire pregnancy. However, this is a longer period than used in previous reports (43-45) and is greater than the minimum four days of SWA data that been reported to adequately represent PA in women (46). While the sample size was small, the high rate of compliance and good distribution of BMI, GWG, and PA levels across
participants leads us to believe that the data is likely to represent regular behavior.

Additionally, the models created were intended to solely predict the outcome of GWG, but the current findings warrant further investigation of PA and dietary intake including quality with respect to predicting other maternal and infant outcomes such as blood glucose control, gestational diabetes mellitus, pre-eclampsia, and offspring adiposity. The exclusion of three women with a BMI in the obese class II category possibly indicated they have a different weight gain profile than other women. Thus, future studies should assess predictors of GWG within each class of obesity.

The findings of this study present evidence that a variety of lifestyle choices can lead to appropriate GWG. However, monitoring protein and CHO intake in early and late pregnancy, respectively, in addition to maintaining or adopting an active lifestyle are potentially initial strategies which could be used in a clinical setting to prevent excessive GWG. CHO intake and quality should be considered along with total daily activity to achieve optimal prenatal health.
References


### Table 1 - Total energy intake and macronutrient distribution in healthy, pregnant women\textsuperscript{a,b}

<table>
<thead>
<tr>
<th>Diet Composition\textsuperscript{c}</th>
<th>Gestation Length (weeks)</th>
<th>P-Values\textsuperscript{d}</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Week 18</td>
<td>Week 35</td>
</tr>
<tr>
<td>Energy Intake (kcal·d\textsuperscript{-1})</td>
<td>2166 (1991-2538)</td>
<td>2250 (2068-2708)</td>
</tr>
<tr>
<td>Protein Intake (g·d\textsuperscript{-1}) [% of total energy]</td>
<td>81.8 (72.3-96.1)</td>
<td>87.3 (74.4-106.4)</td>
</tr>
<tr>
<td></td>
<td>16 (14-17)</td>
<td>15 (13-17)</td>
</tr>
<tr>
<td>CHO Intake (g·d\textsuperscript{-1}) [% of total energy]</td>
<td>299.3 (250.1-336.1)</td>
<td>315.7 (272.1-352.8)</td>
</tr>
<tr>
<td></td>
<td>54 (49-58)</td>
<td>54 (50-57)</td>
</tr>
<tr>
<td>Total Fat Intake (g·d\textsuperscript{-1}) [% of total energy]</td>
<td>79.8 (65.9-94.3)</td>
<td>84.2 (72.0-98.5)</td>
</tr>
<tr>
<td></td>
<td>32 (29-35)</td>
<td>33 (29-35)</td>
</tr>
</tbody>
</table>

\textsuperscript{a}(wk 18: n=36; wk 35: n=32); \textsuperscript{b}Under-reporters (wk 18: n=7; wk35: n=11) and outliers (n=3 wk 18 and 35) removed from analysis; \textsuperscript{c}values are reported in medians (25th-75th percentile); \textsuperscript{d}Statistic from paired t-test
Table 2 - HEI scores of across pregnancy

<table>
<thead>
<tr>
<th>HEI Score (points)</th>
<th>Gestation Length (weeks)</th>
<th>P-Value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Week 18</td>
<td>Week 35</td>
</tr>
<tr>
<td>Total Fruit (includes 100% juice)</td>
<td>4.5 (3.3-5.0)</td>
<td>3.5 (2.8-5.0)</td>
</tr>
<tr>
<td>Whole Fruit (not juice)</td>
<td>5.0 (2.9-5.0)</td>
<td>5.0 (3.3-5.0)</td>
</tr>
<tr>
<td>Total Vegetables</td>
<td>2.2 (1.2-3.3)</td>
<td>2.1 (1.2-2.8)</td>
</tr>
<tr>
<td>Dark Green &amp; Orange vegetables &amp; legumes</td>
<td>1.7 (0.5-3.1)</td>
<td>1.3 (0-2.8)</td>
</tr>
<tr>
<td>Total Grains</td>
<td>5.0 (5.0-5.0)</td>
<td>5.0 (4.9-5.0)</td>
</tr>
<tr>
<td>Whole Grains</td>
<td>2.4 (0.9-3.1)</td>
<td>2.0 (0.5-3.7)</td>
</tr>
<tr>
<td>Milk</td>
<td>8.6 (7.2-10.0)</td>
<td>9.3 (7.2-10.0)</td>
</tr>
<tr>
<td>Meat &amp; Beans</td>
<td>7.9 (5.7-10.0)</td>
<td>7.9 (6.5-9.6)</td>
</tr>
<tr>
<td>Oils</td>
<td>1.9 (0-3.4)</td>
<td>1.9 (0.9-4.3)</td>
</tr>
<tr>
<td>Saturated fat intake</td>
<td>5.5 (3.5-8.2)</td>
<td>7.5 (3.9-8.3)</td>
</tr>
<tr>
<td>Sodium intake</td>
<td>3.8 (2.4-6.0)</td>
<td>4.3 (2.7-5.7)</td>
</tr>
<tr>
<td>Calories from Solid Fat, Alcohol, and Added Sugar (SoFAAS)</td>
<td>10.7 (7.0-13.0)</td>
<td>10.8 (7.5-13.8)</td>
</tr>
<tr>
<td>HEI-05 Score</td>
<td>57.9 (49.6-65.8)</td>
<td>59.9 (48.1-65.6)</td>
</tr>
</tbody>
</table>

^a(wk 18: n=36; wk 35: n=32); ^bvalues are reported in medians (25th-75th interquartile range); ^cHEI score range 0-5; ^dHEI score range 0-10; ^eHEI score range 0-20; ^fHEI score range 0-100; ^gStatistic from paired t-test; ^hStatistic from Wilcoxon rank-sum test
Table 3 - Weight gain according to 2009 IOM GWG guidelines by pre-pregnancy BMI<sup>a,b</sup>

<table>
<thead>
<tr>
<th>Pre-pregnancy BMI (n)</th>
<th>Week 18</th>
<th></th>
<th></th>
<th>Week 35</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>% Under Guideline (n)</td>
<td>% Met Guideline (n)</td>
<td>% Exceeded Guideline (n)</td>
<td>% Under Guideline (n)</td>
<td>% Met Guideline (n)</td>
<td>% Exceeded Guideline (n)</td>
</tr>
<tr>
<td>Underweight&lt;sup&gt;c&lt;/sup&gt; (n=1)</td>
<td>100 (1)</td>
<td>0 (0)</td>
<td>0 (0)</td>
<td>100 (1)</td>
<td>0 (0)</td>
<td>0 (0)</td>
</tr>
<tr>
<td>Normal Weight&lt;sup&gt;d&lt;/sup&gt; (n=30)</td>
<td>23 (7)</td>
<td>47 (14)</td>
<td>30 (9)</td>
<td>13 (4)</td>
<td>53 (16)</td>
<td>33 (10)</td>
</tr>
<tr>
<td>Overweight&lt;sup&gt;e&lt;/sup&gt; (n=9)</td>
<td>11 (1)</td>
<td>44 (4)</td>
<td>44 (4)</td>
<td>11 (1)</td>
<td>0 (0)</td>
<td>89 (8)</td>
</tr>
<tr>
<td>Obese I&lt;sup&gt;f&lt;/sup&gt; (n=3)</td>
<td>0 (0)</td>
<td>0 (0)</td>
<td>100 (3)</td>
<td>0 (0)</td>
<td>0 (0)</td>
<td>100 (3)</td>
</tr>
<tr>
<td>Obese II&lt;sup&gt;g&lt;/sup&gt; (n=3)</td>
<td>100 (3)</td>
<td>0 (0)</td>
<td>0 (0)</td>
<td>67 (2)</td>
<td>33 (1)</td>
<td>0 (0)</td>
</tr>
</tbody>
</table>

<sup>a</sup>Weight used for comparison to recommendations was adjusted to reflect weight gain at exactly week 18 and 35 of gestation; <sup>b</sup>n=46; <sup>c</sup><18.5 kg/m<sup>2</sup>; <sup>d</sup>18.5-24.9 kg/m<sup>2</sup>; <sup>e</sup>25.0-29.9 kg/m<sup>2</sup>; <sup>f</sup>30.0-34.9 kg/m<sup>2</sup>; <sup>g</sup>≥35.0 kg/m<sup>2</sup>
Table 4 - Physical activity (MET-minutes·d\(^{-1}\)) and carbohydrate (CHO) intake (g·d\(^{-1}\)) needed to achieve appropriate gestational weight gain at week 35 using participant daily PA and CHO intakes

<table>
<thead>
<tr>
<th>Pre-pregnancy BMI</th>
<th>Observed Average CHO Intake g·d(^{-1})</th>
<th>Observed Average MET-minutes·d(^{-1})</th>
<th>Recommended weight gain at week 35 (lb)</th>
<th>Recommended CHO intake (g·d(^{-1})) to achieve recommended weight gain given average MET-minutes·d(^{-1})</th>
<th>Recommended MET-minutes·d(^{-1}) to achieve recommended weight gain given average CHO intake (g·d(^{-1}))</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal Weight</td>
<td>317.7</td>
<td>1851</td>
<td>18.8-29.7</td>
<td>155.1 to 386.6</td>
<td>2267 to 1675</td>
</tr>
<tr>
<td>Overweight</td>
<td>327.9</td>
<td>1644</td>
<td>12.7-21.7</td>
<td>-54.9 to 122.8</td>
<td>2623 to 2169</td>
</tr>
<tr>
<td>Obese Class I</td>
<td>306.4</td>
<td>1337</td>
<td>9.7-18.1</td>
<td>-239.2 to -61.5</td>
<td>2733 to 2279</td>
</tr>
</tbody>
</table>
Figures

Figure 1 - Number of participants in the analysis of physical activity and diet based on criteria for valid data

Complete data sets: 
n=48

Eliminated from all analysis for general incompliance: n=2

Physical activity analysis

SWA: valid data (<72 min OBT for ≥4d) 
n=46

Wk 18 participants with valid data: n=46
# of valid days: 
4d: n=0
5d: n=4
6d: n=42
Participants with invalid data: n=0

Wk 35 participants with valid data: n=46
# of valid days: 
4d: n=3
5d: n=4
6d: n=40
Participants with invalid data: n=0

ActivPAL (follows valid SWA days) 
n=46

Wk 18 participants with valid data: n=43
# of valid days: 
4d: n=0
5d: n=4
6d: n=39
Participants with no file: n=3

Wk 35 participants with valid data: n=43
# of valid days: 
4d: n=3
5d: n=3
6d: n=37
Participants with no file: n=3

Diet analysis

Wk 18 participants with valid data: n=46
HEI 2005 
n=37

Wk 35 participants with valid data: n=46
HEI 2005 
n=34

Underreporters 
n=9

Underreporters 
n=12
Figure 2a - Isolines of recommended gestational weight gain at week 18 as predicted by protein intake (g·d\(^{-1}\)) and total activity (MET-minutes·d\(^{-1}\)) predict week 18 gestational weight gain by pre-pregnancy BMI category
Figure 2b: Isolines of recommended gestational weight gain at week 35 as predicted by carbohydrate intake (g·d⁻¹) and total activity (MET-minutes·d⁻¹) predict week 35 gestational weight gain by pre-pregnancy BMI category.
CHAPTER 5. CONCLUSION

Conclusion

Many adverse maternal and fetal health outcomes can be linked back to excessive GWG (1-8), yet the ideal diet and activity prescription necessary to achieve appropriate weight gain has not been identified. Although PA and dietary intake have been shown to predict excessive GWG, the current study demonstrates that the assessment of dietary quality and PA subcomponents, including sedentary behavior, should be evaluated to identify preventative measures that can be taken during prenatal care.

To our knowledge, this is the first study to evaluate total daily activity using objective, 24-hour monitoring periods including sleep, sedentary, light, moderate, and vigorous activity, in addition to diet quality and composition, with respect to predicting GWG. The current study was a prospective, longitudinal design and provided information on total activity over a 24-hour period. Results reported in the first manuscript (Chapter 3) revealed that 65% and 61% of participants met the 2008 DHHS prenatal PA recommendations by week 18 and 35, respectively. However, these women also spent more than half of their total day, and approximately 75% of their time awake, in sedentary behaviors. Additionally, this study demonstrated that 61% and 63% of women during their 2nd and 3rd trimester, respectively, are not getting at least 7 hours of sleep at night, which is categorized as a SB yet sleep is necessary for optimal health. Although SB has been previously recognized as a health hazard in non-pregnant adults (64-69), the current study provides evidence that SB should be considered as a possible contributor when evaluating pregnancy outcomes. Furthermore, this study demonstrates the importance of assessing sleep and nap duration as part of total daily activity and SB with respect to prenatal outcomes.
Although little is known about the effect of behavior other than moderate PA on GWG, the results described in the second manuscript (Chapter 4) demonstrate the importance of quantifying total daily PA to reflect the sum of all activity subcomponents. Two models were developed to predict weight gain at week 18 and 35 of gestation using non-obese and obese class I participants. Total daily MET-minutes, which significantly decreased across pregnancy, were used as a singular measure to represent total activity over a 24-hour period and were predictive of GWG during both the 2\textsuperscript{nd} and 3\textsuperscript{rd} trimester. Protein intake (g/day), after accounting for naps (min/day), and CHO intake (g/day), were positively associated with GWG at week 18 and 35, respectively. However, all subcomponents of activity (sedentary, light, moderate, vigorous, sleep) and measures of diet quality did not emerge as significant predictors of excessive GWG at either time point. Therefore, total activity may provide a more comprehensive picture of lifestyle during pregnancy and as a result, may serve as an important predictor of GWG than moderate PA alone. The resulting models to predict GWG at week 18 and 35 provide preliminary data for an approach that could be incorporated into clinical practice to prevent excessive GWG.

The findings of this study present evidence that a variety of lifestyle choices can lead to appropriate GWG. However, monitoring CHO intake and maintaining or adopting an active lifestyle are potentially initial strategies which could be used in a clinical setting to prevent excessive GWG. Future studies should assess CHO intake and total daily activity with respect to additional acute and chronic pregnancy-related outcomes.
APPENDIX A. RECRUITMENT MATERIALS

IRB ID:

Principal Investigator (PI): Christina Campbell, PhD, RD

Purpose of the Study: We are conducting an observational research study to better understand physical activity in pregnant women.

Description of Research Procedures:

Participants meeting the initial requirements and providing consent will be asked to complete a medical history questionnaire. She will also be asked to provide contact for her medical provider in order to confirm qualification criteria, collect her weight from the first prenatal visit, and her weight from her last prenatal appointment prior to delivery.

The study is observational and participants will not be asked to modify their lifestyle. Each participant will be weighed; complete a 7-day/24-hour physical activity record, a weighed 3 day diet record, and pregnancy Physical Activity Questionnaire for the current trimester; and wear 3 sensors to assess physical activity patterns over a 7-day monitoring period at weeks 17-19 and 34-36 of their pregnancy. The sensors will be worn on the left arm over the triceps muscle (SenseWear Mini armband), ankle (StepWatch) and on the leg over the quadriceps muscle (activPAL). All of these monitors have been used successfully in ISU research studies. Participants will report to the Nutrition Wellness Research Center either on campus or at the external location at the beginning and end of each 7-day monitoring period.

Birth outcome data (APGAR scores, birth weight, birth length, head circumference, gender, and gestational length at delivery) will be collected from the participants' medical records at the delivering hospital following completion of a Release of Medical Record form at enrollment.

Participant Requirements:

Qualification Criteria Includes:

- Must be pregnant (before week 19) and between the ages of 18-45
- Non-smoker
- Pregnant with only one baby
- No history of chronic disease (e.g. Type 1 diabetes, heart disease, renal disease, untreated thyroid condition)
- Able to communicate without language or mental status barriers
- Approval from your medical provider confirming you meet the qualification criteria will be required

No change to your lifestyle will be asked of you; a maximum of 4 study sessions required.

Compensation: Eligible participants will be compensated.

Contact for more information about the study: Contact the Recruitment Team at blossomproject@iastate.edu or 515-294-8673

Deadline for Application to Participate: Enroll by January 2013
The Blossom Project: Assessment of Physical Activity Patterns in Pregnant Women

Thank you for your interest in The Blossom Project! My name is [INSERT NAME HERE] and I am the recruitment coordinator for The Blossom Project here at Iowa State University.

Here is more information about this study:

The purpose of this study is to document the physical activity patterns in pregnant women. You may participate in physical activities that you choose or have been recommended to you by your medical provider and you feel comfortable doing. We will not ask you to modify your current activity. You will need to fill out various questionnaires related to your medical history and/or pregnancy.

You will be asked to visit our research center in Ames at ISU or Iowa Methodist Hospital in downtown Des Moines, whichever is more convenient for you, for 2 data collection periods during your pregnancy: (weeks 17-19 and 34-36 of your pregnancy).

During each of these periods the following data will be collected:

- Height
- Weight
- Physical activity assessment via 3 activity monitors worn on your arm, ankle, and thigh for 7-days
- Record all physical activities in a log for 7-days
- Complete a weighed 3-day diet record
- A questionnaire regarding physical activity during the current trimester of pregnancy

Additionally, the following data will be collected to assess birth outcomes:

- APGAR scores
- Birth weight
- Birth length
- Head circumference
- Gestational length at delivery
- Gender

To qualify for our study you must be:

- Pregnant (prior to 19th week of pregnancy);
- Between the ages of 18-45 years old;
- Not pregnant with multiple babies (e.g. twins);
- Not a smoker;
- No history of chronic disease (e.g. Type 1 diabetes, heart disease, renal disease, untreated thyroid condition);
- Able to communicate without language or mental status barriers
For your participation, you will receive gifts following the completion of all data collection periods. Upon completion of both data collection periods, return of all equipment and communication notifying the research team that the baby was born, you will also receive $50.

I am attaching the consent form which provides more detailed information. I'll be happy to answer any more questions that you may have.

Please email me at [INSERT EMAIL HERE] if you have further questions. Also, let me know whether you are or are not interested in participating. I look forward to hearing from you soon!

Thanks!

[INSERT NAME HERE]
Blossom Project Recruitment Coordinator
Iowa State University
515-294-8673
blossomproject@iastate.edu
The Blossom Project

We are conducting an observational research study to better understand physical activity in pregnant women.

QUALIFICATION CRITERIA INCLUDES:
- Must be pregnant (before week 19) and between the ages of 18-45
- Non-smoker
- Pregnant with only one baby
- No history of chronic disease (e.g. Type 1 diabetes, heart disease, renal disease, untreated thyroid condition)
- Able to communicate without language or mental status barriers
- Approval from your medical provider confirming you meet the qualification criteria will be required

No change to your lifestyle will be asked of you;
A maximum of 4 study sessions required.
Eligible participants will be compensated. Participation is voluntary.

For further information:
Contact the Recruitment Team at blossomproject@iastate.edu or 515-294-8673

Iowa State University
Of Science and Technology
Are you or is someone you know PREGNANT?

The Blossom Project

We are conducting an observational research study to better understand physical activity in pregnant women.

QUALIFICATION CRITERIA INCLUDES:

- Must be pregnant (before week 19) and between the ages of 18-45
- Non-smoker
- Pregnant with only one baby
- No history of chronic disease
  (e.g. Type 1 diabetes, heart disease, renal disease, untreated thyroid condition)
- Able to communicate without language or mental status barriers
- Approval from your medical provider confirming you meet the qualification criteria will be required

No change to your lifestyle will be asked of you; A maximum of 4 study sessions required.
Eligible participants will be compensated. Participation is voluntary.

For further information:
Contact the Recruitment Team at blossomproject@iastate.edu or 515-294-8673

IOWA STATE UNIVERSITY
OF SCIENCE AND TECHNOLOGY
The Blossom Project

Recruiting Cheat Sheet

We are recruiting 80 subjects that meet the following criteria:

- Prior to week 19 of their pregnancy
- 18-45 years old
- Pregnant with only one baby
- English speaking
- No history of chronic disease (e.g. DM1, CVD, CRKD, untreated thyroid conditions)
- Non-smoking

Participation is voluntary.
Compensation is provided.

For further information contact the Recruitment Team at:
blossomproject@iastate.edu or 515-294-8873

IOWA STATE UNIVERSITY
OF SCIENCE AND TECHNOLOGY
**PREGNANT WOMEN NEEDED!**

*We are conducting an observational research study to better understand physical activity in pregnant women.*

QUALIFICATION CRITERIA INCLUDES:

- Must be pregnant (before week 19) and between the ages of 18-45
- Non-smoker
- Pregnant with only one baby
- No history of chronic disease
  - (e.g. Type 1 diabetes, heart disease, renal disease, untreated thyroid condition)
- Able to communicate without language or mental status barriers
- Approval from your medical provider confirming you meet the qualification criteria will be required

No change to your lifestyle will be asked of you;
A maximum of 4 study sessions required.

Eligible participants will be compensated. Participation is voluntary.

*For further information:*
Contact the Recruitment Team at blossomproject@iastate.edu or 515-294-8673

ISU IRB # 1
Approved Date:
Expiration Date:
Initial by:
APPENDIX B. ENROLLMENT DOCUMENTS

CONSENT FORM FOR:
THE BLOSSOM PROJECT
Assessment of physical activity patterns in pregnant women

This form describes a research project. It has information to help you decide whether or not you wish to participate. Research studies include only people who choose to take part—your participation is completely voluntary. Please discuss any questions you have about the study or about this form with the project staff before deciding to participate.

Who is conducting this study?
Christina Gayer Campbell, PhD, RD
Associate Professor, Nutrition
Department of Food Science and Nutrition
Mailing Address: 220 MacKay Hall
Physical Address: 1105 Human Nutrition Science Building
Iowa State University
Ames, IA 50011-1123
515-294-4260; ccampbel@iastate.edu.

What is the purpose of this study?
The purpose of this study is to document the physical activity patterns in pregnant women.

Why am I invited to participate in this study?
You are being asked to take part in this study because you are a healthy woman living in the communities in and around Ames, IA who has shown interest in our study by responding to our recruiting efforts. You have been selected to participate based on several criteria including:

• Between 18-45 years of age;
• Pregnant prior to 19 weeks gestation;
• Not pregnant with multiple babies (e.g. twins);
• Not a smoker; and
• No history of chronic diseases (e.g. Type 1 diabetes, heart disease, renal disease, untreated thyroid condition).
• Able to communicate without language or mental status barriers

What will I be asked to do?
If you agree to participate, you will be asked to do the following:

You will be required to receive confirmation that you are healthy enough to participate in this study from your medical provider. At your first visit, you will need to provide contact information (including name and phone number) for your medical provider. The attached consent letter will be sent by the principal investigator to your medical provider and returned via fax to a member of the project staff. This form will request your weight at your first prenatal appointment. A similar form will be sent to your medical provider after delivery of your baby to obtain your weight at the last prenatal appointment.
Throughout your pregnancy
You may participate in physical activities that you choose or have been recommended to you by your medical provider and you feel comfortable doing. We will not ask you to modify your current activity. You will need to fill out various questionnaires related to your medical history and/or pregnancy. At any time you are invited to discuss concerns that you have about the study protocol; however, the project staff will not make any physical activity recommendations.

At weeks 17-19 & 34-36 of your pregnancy
Your participation in this study may last up to five months (e.g., 17th week of pregnancy to delivery of your baby). There will be two data collection periods and 2 visits required at each period: 1) data initiation, described below & 2) return of equipment. During weeks 17-19 & 34-36 of your pregnancy you will be asked to meet with a member of the project staff at the Nutrition and Wellness Research Center (2325 N. Loop Drive #6146, Ames, Iowa) or the facility located on campus in the Human Nutritional Sciences Building (HNSB) rooms 2021, 2022, and 2023. For your convenience, please provide us with a contact number to facilitate scheduling. You will be asked to schedule a 30-45 minute meeting to receive instructions regarding the physical activity data collection.

During the visit you will be given three activity monitors, a 7-day physical activity record, and a scale to complete a 3-day food log. You will have a weight measurement taken and complete a physical activity questionnaire.

You will be provided with a SenseWear® Mini physical activity armband that is worn on the upper left arm over the triceps muscle. The activity monitor will be worn for 7 days, 24 hours a day to ensure the best possible data collection. The monitor is not water resistant and needs to be removed when showering and swimming. This activity monitor has been used in many studies at ISU with minimal complaints.

You will be provided with a StepWatch that is worn on the ankle to count the number of steps taken daily. The StepWatch will be worn for 7 days, 24 hours a day except when showering and swimming since it is not waterproof. This monitor has also been used in studies at ISU with minimal complaints.

You will be provided with an activPAL activity monitor that is worn on the upper leg over the quadriceps muscle. The activPAL will be worn for 7 days, 24 hours a day, except when showering and swimming since it is not waterproof. It will be attached to your leg using an adhesive pad.

The 7-day physical activity record requires you to record all of your daily activities into a log that will be provided for the same 7 consecutive days you wear the 3 activity monitors. No recommendations for physical activity will be provided to you through this study.

The 3-day food log requires you to weigh and record all food and beverages consumed for 2 weekdays and one weekend day. You will be given detailed instructions on how to properly complete the forms and tips on accurately weighing food. You will be provided with a dietary scale, at no cost to you, for use during the study to facilitate the process. You may perceive this to be a tedious process; however it is the most accurate means of collecting dietary intake information. You will not be given a diet to follow; observations are made on what you typically choose to eat.
The Pregnancy Physical Activity Questionnaire (PPAQ) is a self-administered survey used to assess your physical activity patterns during the current trimester of pregnancy. It will provide information on time spent in the following types of activities: household/caregiving, occupational, sports/exercise, sedentary, light, moderate, and vigorous activity.

You will need to arrange a time with a member of the project staff to turn in your 7-day physical activity record, SenseWear Mini armband, StepWatch, and activPAL at the end of the data collection period.

Birth outcome data
We will be collecting birth outcome data including APGAR scores, birth weight, birth length, head circumference, gender, and gestational length at delivery. This information will be obtained from the official medical record at your delivering hospital. You will be asked to fill out a Release of Medical Record form to allow us to contact the hospital and obtain this information after you have delivered. You will need to notify the Blossom Project research team of your delivery. The form of communication and timing of the completion of the medical release form will depend on where you deliver your baby (see below for details). Consent to participate in this study allows the investigators to contact you following your due date if we have not heard from you.

If you deliver at Mary Greeley Medical Center, Mercy Hospital in Des Moines, or other hospitals in the area with similar medical release protocols:
The research team will provide you with a medical release form and self-addressed stamped envelope at your week 34-36 appointment. You will return the completed form to the Blossom Project AFTER your delivery using the provided envelope. These hospitals require a medical release form be completed after you deliver because your child’s information (name, date of birth) is required. Following these procedures fulfills your responsibility to notify the research team.

If you deliver at Methodist Hospital in Des Moines, or other hospitals in the area with similar medical release form protocols:
At your week 17-19 appointment, you will complete a medical release with your name and contact information. This form will also refer to your baby as “my child” and your signature on this form provides release for both of you. The research team will send you a postcard in the mail near your due date as a reminder to contact us by either phone (515-294-4678) or email (blossomproject@iastate.edu) as soon as possible after you have delivered. The postcard will remind you to provide us with the following information about your child: birth date, gender, and full birth name. The child’s information is needed by the hospital to process the form. Following these procedures fulfills your responsibility to notify the research team.

What are the possible risks and benefits of my participation?
Risks – This is an observational study and it will not provide any risks to you or your baby. This study is looking at what you are doing and does not require you to make any changes to your daily patterns, therefore there are no risks associated with the observational component of the study.

The armband used in this study has been used in other studies within our laboratory with minimal complaints. A few participants have noted a minor skin irritation but it has receded within a couple of days following discontinued use of the monitor. The StepWatch is also
currently being used in other studies in our laboratory with minimal complaints. Removal of the activPAL may cause momentary discomfort since it will be applied with a small adhesive. This discomfort will be similar to that of removing a small Band-Aid.

**Benefits** — You may not receive any direct benefit from taking part in this study. We hope that this research will benefit society by generating data that may contribute to physical activity guidelines during pregnancy.

**How will the information I provide be used?**
The findings of this study will be shared throughout the scientific community via oral and poster presentations at scientific meetings, and published research articles.

**Will I incur any costs from participating or will I be compensated?**
There are no direct costs involved with participating in this study, except your cost of transportation to and from the research facility (e.g. gas money, bus fare). The participant will not be charged to retrieve birth outcome data from the hospital. Any expenses associated with obtaining the medical records will be paid by the Blossom Project. You will be compensated for participating in this study. Throughout the study you will receive “tokens of appreciation”. Upon completing the data collection between weeks 17-19, you will be given a reusable grocery bag and an infant onesie. After the data collection between weeks 34-36, you will receive an infant bib and a coffee mug. All items are imprinted with a Blossom Project logo. Upon completion of both data collection periods, return of all equipment, and using the proper communication (as outlined above) to notify the research team that the baby was born, you will receive $50. If you happen to deliver prior to the week 34-36 data collection period you will be compensated $25 for each period completed. You will need to complete a form at your visit between 34-36 weeks to receive payment. Please know that payments may be subject to tax withholding requirements, which vary depending upon whether you are a legal resident of the U.S. or another country. If required, taxes will be withheld from the payment you receive. If, for any reason, a participant is unable to finish all data collection periods, she will be given the gifts appropriate for the data collection periods that were completed.

**What measures will be taken to ensure the confidentiality of the data or to protect my privacy?**
Records identifying participants will be kept confidential to the extent allowed by applicable laws and regulations. Records will not be made publicly available. However, federal government regulatory agencies, auditing departments of Iowa State University, and the ISU Institutional Review Board (a committee that reviews and approves research studies with human subjects) may inspect and/or copy your records for quality assurance and analysis. These records may contain private information.

To ensure confidentiality to the extent allowed by law, the following measures will be taken: subjects will be assigned a unique code and letter that will be used on forms instead of their name. If the results are published, your identity will remain confidential. The data obtained from the study will be regarded as privileged and confidential. Your privacy will be maintained in any future analysis and/or presentation of the data with the use of coded identifications for each participant’s data. All data will be stored in a locked file cabinet with access only by the principal investigator and project staff. Additionally, any data entered into the computer will be available with restricted password only. This data will be kept on hand until the results of the study have been published in a locked file in the PI's laboratory (HNSB 1109). Identifiers will be kept separate from the data.
What are my rights as a human research participant?
Participating in this study is completely voluntary. You may choose not to take part in the study or to stop participating at any time, for any reason, without penalty or negative consequences. Your choice of whether or not to participate will have no impact on you as a student/employee in any way. You may skip any question during a questionnaire (e.g. medical history, physical activity questionnaire). You may withdraw consent in person or by phone with the principal investigator, Christina Campbell at any time. Please feel free to ask any questions or express your concerns regarding this study. The investigator will attempt to answer all questions. Contact Dr. Christina Campbell at 515-294-4260. If by chance any aspect of the data (e.g. physical activity monitors, physical activity record) are returned with compliance (e.g. wear time) deemed insufficient to the primary investigator, participation in the study may be terminated.

What if I am injured as a result of participating in this study?
Emergency treatment of any injuries that may occur as a direct result of participation in this research is available at the Iowa State University Thomas B. Thienlen Student Health Center, and/or referred to Mary Greeley Medical Center or another physician or medical facility at the location of the research activity.

Whom can I call if I have questions or problems?
You are encouraged to ask questions at any time during this study.

- For further information about the study contact the principal investigator Christina Campbell at 515-294-4260.
- If you have any questions about the rights of research subjects or research-related injury, please contact the IRB Administrator, (515) 294-4566, IRB@iastate.edu, or Director, (515) 294-3115, Office for Responsible Research, Iowa State University, Ames, Iowa 50011.

Consent and Authorization Provisions

Your signature indicates that you voluntarily agree to participate in this study, that the study has been explained to you, that you have been given the time to read the document and that your questions have been satisfactorily answered. You will receive a copy of the written informed consent prior to your participation in the study.

Participant’s Name (printed)

(Participant’s Signature) (Date)

Investigator Statement

I certify that the participant has been given adequate time to read and learn about the study and all of their questions have been answered. It is my opinion that the participant understands the purpose, risks, benefits and the procedures that will be followed in this study and has voluntarily agreed to participate.

(Signature of Person Obtaining Consent) (Date)
Blossom Project Physical Activity Assessment Timeline

Prior to wk 19
- Recruit participants
- Sign consent forms

Weeks 17-19
- Weight measured
- 3d weighed diet record
- 24hr 7d PA log
- Armband activity monitor
- Ankle-worn StepWatch
- activPAL
- PPAQ (pregnancy physical activity questionnaire)

Weeks 34-36
- Weight measured
- 3d weighed diet record
- 24hr 7d PA log
- Armband activity monitor
- Ankle-worn StepWatch
- activPAL
- PPAQ (pregnancy physical activity questionnaire)

Post-Delivery
- Research team is notified of delivery
- Medical release form is submitted to delivering hospital to retrieve the following birth outcomes:
  - APGAR scores at 1 & 5 min
  - Birth weight
  - Birth length
  - Head circumference
  - Gender
  - Gestational length at delivery
Dear Medical Provider,

_________________________ has volunteered to participate in an observational study regarding the assessment of physical activity and sedentary patterns in pregnant women. We will not be providing any exercise recommendations; the study only involves recording what the subject chooses to do on her own. Your patient will complete a 3-day weighed food record, wear a SenseWear® Mini physical activity armband, an ankle-worn research grade pedometer, StepWatch, and an accelerometer-based posture monitor, the activPAL, to detect sedentary time. She will record her daily activities in a 7-day record and complete a physical activity questionnaire to assess physical activity patterns during the current trimester of pregnancy. Your patient will be collecting this data for two 7-day monitoring periods during weeks 17-19 and 34-36 of her pregnancy. Each participant will also be weighed at each time period. This study is approved by the Iowa State University Institutional Review Board.

We would like you to confirm that ________________________ meets the study criteria:

- Between the ages of 18-45;
- Pregnant with only one baby;
- Non-smoker;
- No history of chronic diseases (e.g. Type 1 diabetes, heart disease, renal disease, untreated thyroid condition); and
- Able to communicate without language or mental status barriers

Weight of patient at first prenatal appointment: ___________ Date of appointment: ________________

Signature of Medical Provider: ________________________________________________________________

Print Name: ____________________________ Date: __________________

Please return this form via facsimile as soon as possible. Thank you for your help with this project.

Sincerely,
Christina Campbell, PhD, RD; Associate Professor, Nutrition; Iowa State University
ccampbel@iastate.edu
Phone: 515-294-4280
Fax: 515-294-6193

Signature of research participant providing permission to contact physician & to receive her weight:

Signature: ____________________________ Date: __________________
Dear Medical Provider,

_________ has recently completed an observational study regarding the assessment of physical activity and sedentary patterns in pregnant women. At the beginning of the study we asked your permission for the woman to participate and you provided her weight from her first prenatal visit. In order to accurately assess gestational weight gain, the patient's weight from her last prenatal visit will be necessary. This form is asking for you to document this weight to be used in our final analysis. This study is approved by the Iowa State University Institutional Review Board.

Weight of patient at last prenatal appointment prior to delivery ________________

Date of appointment ______________________

Signature of Medical Provider ________________________________________________

Print Name________________________________________ Date____________________

Please return this form via facsimile as soon as possible. Thank you for your help with this project.

Sincerely,

Christina Campbell, PhD, RD; Associate Professor, Nutrition; Iowa State University
ccampbel@iastate.edu
Phone: 515-294-4260
Fax: 515-294-6193

Signature of research participant providing permission to contact physician & to receive her weight:

Signature: __________________________ Date: __________________________
Medical History Questionnaire

Please answer the following questions to the best of your knowledge. All information provided here is completely confidential. Please ask for clarification if needed.

Subject ID: ____________________

Age: _______yrs_______moDate of Birth: ________________________________

Pre-pregnancy weight:_______________lbsHeight:________ft_________in

Handedness: Right     OR Left

Is this your first pregnancy? YesNo

If no, number of pregnancies (including this one)____________________

Number of live births__________________________

If number of pregnancies and number of live births are not equal to each other, please explain:

___________________________________________________________________
___________________________________________________________________

Birth dates of children
__________________________________________________________
mo/day/yrmo/day/yrmo/day/yrmo/day/yrmo/day/yr

Are you planning to breastfeed?

First day of last menstrual period:__________  Due
Date:__________________________

What is the first day of your next week of pregnancy (i.e. turnover day)? (circle)
Sunday   Monday Tuesday   Wednesday   Thursday   Friday   Saturday

In what week of your pregnancy did you find out you were pregnant?____________________

Prior to your pregnancy what was your average number of workouts per week?______________

Average duration of workout_____________________
Type of activity___________________________________________________________

Since you became pregnant what has been your average number of workouts per week? ______
Average duration of workout__________________________

Type of activity___________________________________________________________

Have you experienced any morning sickness that altered your activity level? Yes No
If yes, please describe____________________________________________________

Are you following any guidelines regarding exercise during your pregnancy?_______
If yes, please describe____________________________________________________

Where did you receive the guidelines?_____________________________________

Race (circle):
1. American Indian or Alaska Native
2. African American
3. Caucasian
4. Asian
5. Hispanic
6. Other (specify):________________

Marital Status (circle):
1. single
2. married
3. divorced/separated
4. widowed

Education Level
What is the last grade in school that you completed? Please specify if two year school (circle)
1. Elementary 01 02 03 04 05 06 07 08
2. High School09 10 11 12
3. College13 14 15 16
4. Graduate/Professional School 17+

Employment:
What is your occupation?____________________________________
If employed how many hours a week do you work?______________
How many adults, age 18 years and older, live in your household? _______
Please include yourself.
How many children, age 17 years and younger, live in your household? __________

What was your total household income in the past year?
1. Less than $25,000
2. $25,000 up to $50,000
3. $50,000 up to $75,000
4. $75,000 or more

Drug and Alcohol:
1. Do you currently take vitamin supplements on a regular basis? ________________
   If yes, please specify _______________________________________________________
   Have you in the past? _________________________________________________________
   If so, how long ago? _________________________________________________________
2. Do you currently take herbal supplements on a regular basis? _________________
   If yes, please specify _________________________________________________________
   Have you in the past? _________________________________________________________
   If so, how long ago? _________________________________________________________
3. Do you currently take any medications on a regular basis? _________________
   If yes, please specify _________________________________________________________
4. Have you taken medication regularly in the past? ___________________________
   If yes, please specify _________________________________________________________
   How long ago was medication taken regularly? ________________________________
5. During your pregnancy are you consuming alcohol? ________________
   If so, how many drinks each week? ___________________________________________
Medical History (circle any, and give age at diagnosis):

Age

1. Diabetes ____
2. Thyroid Disease____
3. Cirrhosis____
4. Hepatitis____
5. Gall Stones____
6. Kidney Stones____
7. Nephritis____
8. Cancer (specify)____
9. High Blood Pressure ____
10. Angina____
11. Allergies (specify)____
12. Goiter____
13. Cardiovascular Disease____
14. Depression requiring medication____
15. Insomnia requiring medication____
16. Gestational Diabetes____
17. Preeclampsia____
18. Previous infant with low birth weight ____
19. Early delivery with previous pregnancy____

If so, please explain:

________________________________________________________________________
________________________________________________________________________
________________________________________________________________________
APPENDIX C. TIMEPOINT DATA COLLECTION DOCUMENTS

BP2 Timepoint Data Sheet

Subject ID: ____________________ Due date: _____________________
Subject DOB: ________________

Week 17-19
Date: ____________________ Gestation length: ____________________
Height (cm): _______________ Weight (kg): ______________________

Week 34-36
Date: ____________________ Gestation length: ____________________
Weight (kg): _______________
Directions for
3-Day Weighed Diet Records

- Please use the scale provided to weigh all food that you eat during your 3 day recording period.

- Keep your food record current. List all foods and supplements immediately after they are weighed. Do not wait until the end of the day to record entries.

- Please print all entries.

- Be as specific as possible when describing the food or beverage:
  - Include the method of preparation used (boiled, baked, broiled, fried, grilled, steamed, raw, etc); example: pork chop, center cut, no bone, grilled
  - Include a well detailed description of the food item (fresh, canned, packed in heavy or light syrup, packed in water or oil, skinless, boneless, cut of meat, brand name); examples: peaches in heavy syrup, tuna in oil, broiled T-bone steak, microwave heated canned corn
  - Include label with the nutritional information for any unusual items or if unsure how to record

- Categorize the food consumed by meal type. Indicate “B” for breakfast, “L” for lunch, “D” for dinner, or “S” for snack.

- Include the name of restaurant if eating out

- Report only the portion of food that was actually eaten; example: T-bone steak, grilled -100g (do not include the weight of the bone)

Example: 100g t-bone- 30g bone=70g actual food consumed
1 - 500 mg multivitamin

- Weigh food left on plate that you did not eat and subtract from original total

- Record amount in either grams or ounces (wt) – please be consistent

- Remember to record condiments (ketchup, soy sauce, mustard, ranch dressing, salt, etc) as well as any fats used in cooking (oils, butter, margarine, etc), it is acceptable to measure these (Tbsp, tsp etc)

- Please try not to alter your normal diet during the period that you keep this record …… Thank you!!!!!!

- If there are any questions please email: blossomproject@iastate.edu
<table>
<thead>
<tr>
<th>B/L/D/S</th>
<th>Time</th>
<th>Food</th>
<th>Constituents</th>
<th>Description</th>
<th>Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>B</td>
<td>9 am</td>
<td>Daily Supplements:</td>
<td>Multivitamin</td>
<td>One a Day multivitamin</td>
<td>1-500 mg capsule</td>
</tr>
<tr>
<td></td>
<td>9am</td>
<td>Grape Nuts</td>
<td></td>
<td>Post Brand</td>
<td>120g</td>
</tr>
<tr>
<td>B</td>
<td>9am</td>
<td>Sugar</td>
<td></td>
<td>White</td>
<td>3g</td>
</tr>
<tr>
<td>B</td>
<td>9am</td>
<td>Milk</td>
<td></td>
<td>1%</td>
<td>106g</td>
</tr>
<tr>
<td>S</td>
<td>9am</td>
<td>Blueberries</td>
<td></td>
<td>Frozen, unsweetened</td>
<td>50g</td>
</tr>
<tr>
<td>S</td>
<td>9am</td>
<td>Orange Juice</td>
<td></td>
<td>Tropicana, no pulp, calcium added</td>
<td>120g</td>
</tr>
<tr>
<td>S</td>
<td>11:30 am</td>
<td>Almonds</td>
<td></td>
<td>Raw, unsalted, Kirkland brand</td>
<td>60g</td>
</tr>
<tr>
<td>L</td>
<td>1:00pm</td>
<td>Sandwich Bread</td>
<td>Bread</td>
<td>Whole Wheat, Wheat Montana</td>
<td>45g</td>
</tr>
<tr>
<td>L</td>
<td>1pm</td>
<td>Sprouts</td>
<td>alfalfa</td>
<td></td>
<td>5g</td>
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<tr>
<td>L</td>
<td>1pm</td>
<td>Cheese</td>
<td>Tillamook Sharp Cheddar</td>
<td></td>
<td>33g</td>
</tr>
<tr>
<td>L</td>
<td>1pm</td>
<td>Ham</td>
<td>Hillshire Farms Honey Ham</td>
<td></td>
<td>15g</td>
</tr>
<tr>
<td>S</td>
<td>1pm</td>
<td>Cottage Cheese</td>
<td></td>
<td>Low fat 2% small curd</td>
<td>55g</td>
</tr>
<tr>
<td>S</td>
<td>1pm</td>
<td>Apple Juice</td>
<td></td>
<td>From concentrate, Apple Tree brand, 100% juice</td>
<td></td>
</tr>
<tr>
<td>B/L/D/S</td>
<td>Time</td>
<td>Food</td>
<td>Constituents</td>
<td>Description</td>
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</table>
Directions for
Activity Monitors and Physical Activity Log

- The SenseWear® armband activity monitor should be placed on the back side (over your triceps muscle) of your left arm between the elbow and shoulder. Adjust the strap so it fits your arm comfortably. Ensure it is contact with your skin at all times and that the monitor is right side up on your arm (the words should not be upside down when viewed in a mirror).
  - There is no on/off button for the activity monitor. It will be collecting data when it is in direct contact with your skin.
  - When the monitor is correctly placed on your arm it will sound off “dee dee dee, dee dee”.
  - If the monitor loses contact with your skin or becomes misplaced from the proper contact site it will sound off “dee dee dee.” Readjust the monitor and listen for the “dee dee dee, dee dee” sound to ensure proper placement.

- The StepWatch ankle-worn pedometer should be placed on your right ankle.
  - Ensure that the arrow and “UP” on the inside of the StepWatch are placed in the right direction (the large arch on the top of the monitor should be on the top when you are wearing the StepWatch.)

- The activPAL activity monitor should be placed on top center of the right thigh approximately 1/3 distance down from the hip bone to the top of the knee cap.
  - The head of the person on the front of the monitor should be right side up.

- Please record each activity as you do it in the physical activity log for 7 days
  - Enter the start and stop time for each activity
  - Include ALL activities throughout your day (showering, eating, driving, sitting at computer, watching tv, cooking dinner, walking to work, etc.)

- After 7 days have passed please be sure to make arrangements with a research investigator to return your materials.

The armband, StepWatch, and activPAL are NOT waterproof! Please do not wear them while showering or swimming or submerge it in other liquid.

Thank you.

**If you develop a skin irritation during the 7 day period, immediately contact a research investigator.

Christina Campbell at 515-520-2326 OR Katie Smith at katiel@iastate.edu
## Physical Activity Log

<table>
<thead>
<tr>
<th>Start Time</th>
<th>End Time</th>
<th>Activity</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>7am</td>
<td>7:30am</td>
<td>Getting dressed/showering</td>
<td>Up and down stairs 2 to 4 times</td>
</tr>
<tr>
<td>7:30</td>
<td>8:00</td>
<td>Making and Eating Breakfast</td>
<td></td>
</tr>
<tr>
<td>8:00</td>
<td>8:25</td>
<td>Drive to work</td>
<td></td>
</tr>
<tr>
<td>8:25</td>
<td>8:30</td>
<td>Walk from car</td>
<td>Quick walk from parking lot up stairs, one flight, to office</td>
</tr>
<tr>
<td>8:30</td>
<td>12:00pm</td>
<td>Working</td>
<td>Mostly sitting at desk or computer</td>
</tr>
<tr>
<td>12:00</td>
<td>1:00</td>
<td>Eating Lunch</td>
<td>Ate lunch and read a magazine</td>
</tr>
<tr>
<td>1:00</td>
<td>5:00</td>
<td>Working</td>
<td>Mostly sitting at desk or computer</td>
</tr>
<tr>
<td>5:00</td>
<td>5:05</td>
<td>Walk to car</td>
<td>Walk to car in parking lot, down one flight of stairs</td>
</tr>
<tr>
<td>5:05</td>
<td>5:45</td>
<td>Errands</td>
<td>Walking around stores, and driving</td>
</tr>
<tr>
<td>5:45</td>
<td>6:30</td>
<td>Swimming</td>
<td>Lap swim mostly freestyle and backstroke about 1000 yards</td>
</tr>
<tr>
<td>6:30</td>
<td>7:30</td>
<td>Making and eating dinner</td>
<td>Standing in kitchen, sitting at table</td>
</tr>
</tbody>
</table>
# Physical Activity Log

<table>
<thead>
<tr>
<th>Date</th>
<th>Start Time</th>
<th>End Time</th>
<th>Activity</th>
<th>Description</th>
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APPENDIX D. STATISTICAL OUTPUTS

Box Plots
Prediction Model Fit Test Results

Week 18

Summary of Fit

RSquare 0.211705
RSquare Adj 0.135418
Root Mean Square Error 2.185766
Mean of Response 4.051429
Observations (or Sum Wgts) 35

Analysis of Variance

<table>
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<tr>
<th>Source</th>
<th>DF</th>
<th>Sum of Squares</th>
<th>Mean Square</th>
<th>F Ratio</th>
<th>Prob &gt; F</th>
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Parameter Estimates

| Term                                           | Estimate   | Std Error | t Ratio | Prob>|t| |
|------------------------------------------------|------------|-----------|---------|-----|
| Intercept                                      | 9.6615311  | 3.907564  | 2.47    | 0.0191* |
| MET-minutes per DAY (SWA)-included est swim, self-care, sleep | -0.004302  | 0.001981  | -2.17   | 0.0376* |
| Wk 18 Avg Protein Intake (g)                   | 0.0343946  | 0.018414  | 1.87    | 0.0713 |
| Min in Naps/SNOS (SWA) per DAY                  | -0.059035  | 0.032996  | -1.79   | 0.0834 |
### Week 35

#### Summary of Fit

- **RSquare**: 0.193095
- **RSquare Adj**: 0.137447
- **Root Mean Square Error**: 3.990109
- **Mean of Response**: 13.3075
- **Observations (or Sum Wgts)**: 32

#### Analysis of Variance

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<tr>
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<td>572.19640</td>
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#### Parameter Estimates

| Term                                                | Estimate   | Std Error  | t Ratio | Prob>|t| |
|-----------------------------------------------------|------------|------------|---------|-----|---|
| Intercept                                           | 20.700975  | 7.281929   | 2.84    | 0.0081* |
| MET-minutes per DAY (SWA)- included est swim, self-care, sleep | -0.008357  | 0.003836   | -2.18   | 0.0376* |
| Wk 35 Avg CHO Intake (g)                            | 0.0213858  | 0.012525   | 1.71    | 0.0984 |