Early Prevention of Childhood Obesity: Impact of Maternal Physical Activity on Pregnancy and Child Outcomes

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Early prevention of childhood obesity: Impact of maternal physical activity on pregnancy and child outcomes

by

Kai Ling Kong

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

DOCTOR OF PHILOSOPHY

Major: Nutritional Sciences

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Iowa State University
Ames, Iowa

2013

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DEDICATION

Dedicated to my Lord and Savior, Jesus Christ

Let all that I am praise the Lord;
with my whole heart, I will praise his holy name.
Let all that I am praise the Lord;
may I never forget the good things he does for me.

Psalm 103: 1-2
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ABSTRACT

Maternal obesity and excessive gestational weight gain cause a perpetuating “vicious cycle” of obesity, where obese women or women who gain excess gestational weight have a higher risk of giving birth to large for gestational age infants, who then, years later, can become obese adults entering into their own pregnancies. Many observational studies have supported the role of physical activity (PA) in helping pregnant women to minimize, if not prevent, excessive gestational weight gain (GWG). Since maternal PA has potential to prevent excessive GWG and decrease the risk for delivering large-for-gestational-age (LGA) infants, identifying strategies to help pregnant women increase their PA participation during gestation becomes critical in light of the increasing obesity prevalence for both adults and children.

The Blossom Project team of Iowa State University conducted a pilot randomized controlled trial entitled ‘Moms to Move’ (M2M). The objectives of M2M study were 1) to promote moderate PA participation among previously non-exercising, overweight and obese pregnant women, via walking.; 2) and to evaluate the impact of increased moderate PA on GWG and birth outcomes. The intervention in this study was a walking program, which participants in the intervention group were informed the current physical activity guidelines, 150 minutes of moderate PA spread through the week, and were given a treadmill for home use. The results of the study showed that there were significantly more moderately intense cadence (cadence $\geq 80$ steps/min) among the women in the intervention group compared to control group at V2 (overweight $p < 0.0001$; obese $p < 0.025$), V3 (overweight $p < 0.0001$; obese $p = 0.0722$), and V4 (overweight $p < 0.0001$; obese $p < 0.025$). Women in the intervention group also significantly increased their meaningful walks at V2 (diff = 32.6
min, \( p = 0.054 \), V3 (diff = 37.1 min, \( p = 0.01 \)) and V4 (diff = 35.4 min, \( p = 0.014 \)). Even though it was not statistically significant, there was a trend for women in the intervention group to have more favorable pregnancy and birth outcomes compared to the control group.

Besides evaluating PA participation of the overweight and obese women during pregnancy, the study was also set forth to compare exercise self-efficacy (barrier self-efficacy and task self-efficacy) of participants in the walking intervention versus non-intervention control group toward the end of the trial, and to examine the relative contribution of pre-pregnancy body mass index (BMI), barrier self-efficacy and task self-efficacy in predicting physical activity amount (step count) at the end of second and late third trimesters of pregnancy using an objective measurement tool. The findings of this study demonstrated that pregnant women in the walking intervention, which started at the beginning of the second trimester (weeks 12-15 of gestation) had a higher barrier and task self-efficacy at the end of second (weeks 27-29) and late third trimester. At V3, task self-efficacy \( (r^2 = 0.254, p < 0.003) \) and barrier self-efficacy \( (r^2 = 0.123, p < 0.049) \) independently predicted step count; however task self-efficacy together with pre-pregnancy BMI explained 30.0\% \( (p < 0.006) \) of the variance, which was selected as the best model to predict step count. At V4, task self-efficacy \( (r^2 = 0.234, p < 0.003) \) and pre-pregnancy BMI \( (r^2 = 0.167, p < 0.015) \) independently predicted step count, and both variables combined explained 35.9\% of the variance \( (p < 0.001) \), which was selected as the best model to predict step count. In summary, task self-efficacy and pre-pregnancy BMI emerged as the major contributors to the prediction at both time points. In other words, task self-efficacy together with pre-pregnancy BMI were the most proximal determinants of PA participation for overweight and obese pregnant women during pregnancy.
Lastly, a follow-up study was conducted at one and six months post-partum to obtain the maternal post-partum weight and child outcomes. The purposes of this follow-up study were 1) to compare maternal weight retention of participants enrolled in the walking intervention during pregnancy versus the control group, as well as their child outcomes (weight-for-length z-score, fat mass and % fat mass); 2) to examine the relationship between pre-pregnancy BMI and rates of GWG at different time points during pregnancy with maternal weight retention and weight-for-length z-scores of infants. At six months post-partum, obese women in the intervention group retained less than 1% of their maternal weight compared to 7% weight retention among obese women in the control group. Obese women in the control group experienced a 3.54% weight gain from one month to six months post-delivery. In contrast, obese women in the intervention group reduced their weight by 1.22% from one month to six months post-delivery. Although not statistically significant, there was a tendency for the offspring of obese women in the intervention group to have lower WLZ scores at one month and six months old. In fact, this trend starts at birth; as obese women who participated in the walking intervention had lower infant birth weight z-scores and decreased odds of fetal macrosomia. In addition, percentage of weight retention and WLZ scores were significantly correlated with rate of GWG especially at the early time points during pregnancy.

Taken together, the findings reported in this dissertation, suggest that targeting PA interventions for overweight and obese women during pregnancy could be a promising starting point for obesity prevention.
CHAPTER 1: GENERAL INTRODUCTION

Introduction

The rate of obesity is rapidly increasing worldwide, and the prevalence of obesity in the United States continues to remain one of the highest (World Health Organization, 2012). In the past two decades, the incidence of obesity among children has also rapidly increased. Within the United States, the National Health and Nutrition Examination Survey (NHANES) 2009 – 2010 showed that 9.7% of infants and toddlers had a high weight-for-recumbent length and 16.9% of children and adolescents from 2 through 19 years of age were obese (Ogden, Carroll, Kit, & Flegal, 2012). These values are concerning, as obese children and adolescents are more likely to become obese adults and possess obesity-associated morbidities (Daniels, 2006).

The development of chronic disease, such as obesity, has largely been attributed to unhealthy lifestyle choices or uncontrollable genetic predispositions. However, emerging evidence reveals that one’s exposure within the intrauterine environment may play a pivotal role in the development and progression of chronic disease (D. J. P. Barker, 2007; Matthew W Gillman, 2005; Oken & Gillman, 2003; Wadhwa, Buss, Entringer, & Swanson, 2009). This theory, the “Developmental Origins of Health and Disease (DOHaD)”, or better known as “Barker’s hypothesis”, proposes intrauterine stress from nutrient deficiency in utero can permanently alter fetal organ systems, a process called fetal programming (D. J. P Barker, Winter, Osmond, Margetts, & Simmonds, 1989; D. J. P. Barker, 2007; Osmond, Barker, Winter, Fall, & Simmonds, 1993). While initially proposed to account for health consequences of small for gestational age infants, the DOHaD hypothesis has been recently used to gain a better understanding of the obesity epidemic (Adamo, Ferraro, & Brett, 2012;
Dabelea & Crume, 2011; Oken & Gillman, 2003). The DOHaD hypothesis elucidates how an unfavorable intrauterine environment due to maternal obesity and excessive gestational weight gain (GWG) increases the risk of obesity in the offspring. These two factors cause a perpetuating “vicious cycle” of obesity, where obese women or women who gain excess gestational weight have a higher risk of giving birth to large for gestational age (LGA) infants, who then, years later, can become obese adults entering their own pregnancies (Oken, 2009a). Higher birth weight is associated with higher attained BMI later in life (Curhan et al., 1996; Dempsey et al., 2004; M W Gillman, Rifas-Shiman, Berkey, Field, & Colditz, 2003; Parsons, Power, Logan, & Summerbell, 1999; F. Rasmussen & Johansson, 1998). In Western and developed countries such as the United States, reproductive-age women are more likely to give birth to LGA infants due to an obesogenic environment (Dabelea & Crume, 2011).

Maternal obesity and excessive GWG are two of the main causes of giving birth to a LGA infant (Adamo et al., 2012; Dabelea & Crume, 2011; Nelson, Matthews, & Poston, 2010; Oken, 2009b). The association of maternal obesity and offspring obesity continues into childhood, as demonstrated by Whitaker and colleagues who found children ages 2 to 4 (n = 8494) born to obese mothers had more than twice the likelihood of being obese. By 4 years of age, one in four children of obese mothers were obese, compared to less than one in ten for normal weight mothers (R C Whitaker, 2004).

Excess GWG also leads to giving birth to LGA infants. Recent reviews (Adamo et al., 2012; Nelson et al., 2010; Poston, 2012) have used epidemiological and observational data to support the relationship between excessive GWG and offspring obesity. Project Viva, a landmark study in the United States, also showed that GWG is directly associated
with a child being overweight at age 3 (OR 1.30; 95% CI: 1.04 – 1.62 for each 5 kg of GWG) even after adjusting for sociodemographic factors, breastfeeding duration, glucose tolerance, and gestation length (Oken, Taveras, Kleinman, Rich-Edwards, & Gillman, 2007). These findings support the conclusion that women should avoid excessive weight gain in early pregnancy and that overweight or obese women should avoid excessive GWG at all costs.

Weight gain and obesity occur when energy intake exceeds energy expenditure, resulting in an energy imbalance. It is well established that healthy eating habits and regular physical activity (PA) are two modifiable targets in preventing excessive weight gain and should be encouraged among pregnant women. Physical activity during pregnancy has been viewed as an important part of reproductive health. According to the American College of Obstetrics and Gynecology (ACOG) 2002 guidelines, in the absence of medical or obstetric complications, pregnant women can accumulate 30 minutes or more of moderate-intensity exercise on most, if not all, days of the week (ACOG Committee Obstetric Practice, 2002). The risks of moderate-intensity activity performed by healthy women during pregnancy are very low, and it does not increase the risk of low birth weight, preterm delivery, or early miscarriage (Downs, Chasan-Taber, Evenson, Leiferman, & Yeo, 2012). However, pregnancy itself is a life event which leads to decreases in exercise among many women (Brown & Trost, 2003; Godin, Vezina, & Leclerc, 1986; Mottola, 2002). The main exception to this finding is walking, a common and popular choice of PA during pregnancy. When Mottola and Campbell evaluated activity patterns during pregnancy, they found that all categories of activity decreased except walking, which actually increased significantly by the 3rd trimester among the 529 women they surveyed (Mottola & Campbell, 2003). Many
observational studies have supported the role of PA in helping pregnant women to minimize, if not prevent, excessive GWG (J. Clapp & Little, 1995; Haakstad, Voldner, Henriksen, & Bø, 2007; Olson & Strawderman, 2003; Stuebe, Oken, & Gillman, 2009). Since maternal PA has potential to prevent excessive GWG, decreasing the risk for delivering LGA infants, identifying strategies to help pregnant women increase their PA participation during gestation becomes critical in light of the increasing obesity prevalence.

**Dissertation Organization**

This dissertation contains a general introduction, a literature review, and three manuscripts, followed by a general conclusion. Three manuscripts represent each chapter of the dissertation. The second chapter, “A randomized-controlled walking intervention to improve pregnancy and birth outcomes by promoting moderate physical activity among overweight and obese pregnant women: Moms to Move (M2M) study”, will be submitted to the journal Medicine and Science in Sports and Exercise. The third chapter, “Objectively measured step count can be predicted by self-efficacy and pre-pregnancy BMI among overweight and obese pregnant women in a randomized-controlled trial”, has been submitted to the International Journal of Behavioral Nutrition and Physical Activity. The fourth chapter, “Impact of a walking intervention during pregnancy on post-partum weight retention and infant outcomes”, will be submitted to journal Obesity. Lastly, the appendices contain all of the approved documents for the study by the Institutional Review Board of Iowa State University, and the blood profiles of the participants, which are not included in any of the aforementioned, but will be included in an additional manuscript that is still in the developmental stages.
CHAPTER 2: LITERATURE REVIEW

Obesity Overview

Overweight and obesity are defined as abnormal or excessive fat accumulation that may cause adverse health outcomes (World Health Organization, 2012). In adults, Body Mass Index (BMI: weight in kilograms divided by the square of the height in meters, kg/m$^2$) is used to classify an individual as underweight (BMI < 18.5 kg/m$^2$), normal weight (BMI 18.5-24.9 kg/m$^2$), overweight (BMI 25.0-29.9 kg/m$^2$) or obese (BMI ≥30.0 kg/m$^2$). Obesity is further classified into three levels: Class I obesity (BMI 30.0-34.9 kg/m$^2$), Class II obesity (BMI 35.0-39.9, kg/m$^2$) and Class III (BMI ≥ 40.0 kg/m$^2$). In children and adolescents (aged 2 – 19 years), weight status is determined using an age- and sex-specific percentile for BMI as children’s body composition varies at different ages and between the genders (Centers for Disease Control and Prevention, 2012a). Body mass index between 85th to 95th percentiles is classified as overweight, and BMI above 95th percentile is classified as obese among children.

According to the World Health Organization (WHO), in 2008 more than 1.5 billion adults ages 20 and older were classified as overweight and 500 million were identified as obese (World Health Organization, 2012). Obesity is considered a major public health problem in developed, industrialized countries, primarily the United States and Europe. More recently, developing countries like Mexico, China, and Thailand have seen the most dramatic increases in obesity rates (Popkin & Gordon-Larsen, 2004). A phenomenon known as the nutrition paradox is observed in many developing countries (Caballero, 2005). In these countries, the issues of hunger and obesity co-exist not only in different regions of the country, but within the same family. Despite the increasing rate of obesity worldwide, the
prevalence of obesity in the United States continues to be one of the highest (World Health Organization, 2011). According to the latest data from U.S. Centers for Disease Control and Prevention (CDC), more than one-third of the U.S. adults are obese (Centers for Disease Control and Prevention, 2012b). Obesity rates in the United States range from 34.9% in Mississippi (highest) to 20.7% in Colorado (lowest) and clinically severe (>100 lbs. [45 kg] overweight) obesity rates continue to increase rapidly. In 2000, 3.9% of U.S. adults had a BMI 40 kg/m² or greater, this percentage grew to 6.55% by 2010 (Sturm & Hattori, 2012). A report released by Trust for America’s Health (TFAH) and the Robert Wood Johnson Foundation (RWJF) in 2012 indicated that if obesity rates continue to follow current trends, 39 states could have obesity rates above 50%, with the highest at 66.7% (Mississippi) and lowest at 44.8% (Colorado) (F as in fat: how obesity threatens America’s future 2012, 2012).

In the past two decades, the incidence of obesity among children has started to increase. In 2010, more than 43 million children under the age of five were overweight worldwide (World Health Organization, 2012). In the United States, the National Health and Nutrition Examination Survey (NHANES) 2009-2010 showed that 9.7% of infants and toddlers had a high weight-for-recumbent length and 16.9% of children and adolescents from 2 through 19 year old were obese (Ogden et al., 2012). Interestingly, this data had not changed compared to 2007-2008 NHANES data despite the vigorous effort put forth by the government and different institutes. Childhood and adolescent obesity continues to be a major concern as research has indicated obese children and adolescents are more likely to become obese adults and possess obesity-associated morbidities (Daniels, 2006).
Obesity markedly impairs overall quality of life (Fontaine & Barofsky, 2001). It is associated with increased risk of type 2 diabetes (Eckel et al., 2011), cardiovascular disease (Krauss, Winston, Fletcher, & Grundy, 1998), mental disease (Scott, McGee, Wells, & Oakley Browne, 2008), certain types of cancer (Vucenik & Stains, 2012), as well as overall mortality (Allison, Fontaine, Manson, Stevens, & VanItallie, 1999). The health care costs of obesity-related diseases has become a severe burden to the government and society (Voelker, 2012). It is estimated that, by 2030, the price tag of treating obesity related diseases will add up to $66 billion if current trends are not halted. The medical costs for an obese person are estimated to be $1429 higher than a normal weight individual (Centers for Disease Control and Prevention, 2012b).

**Maternal Obesity**

**A) Overview of the prevalence**

The rate of obesity in women is alarming. Among the 1.5 billion overweight individuals worldwide, 300 million of them were obese women in 2008 (World Health Organization, 2012). As a result, the population of obese childbearing women is also increasing (Zera, McGirr, & Oken, 2011). In the United States, approximately two-thirds of childbearing age women were either overweight or obese in 1999-2004. For women, Class I and II obesity doubled and class III obesity tripled between 1979 and 2004 (K. Rasmussen & Yaktine, 2009). Flegal and colleagues reported that 14.7% of women aged 20 to 39 years had a BMI 30-34.9 kg/m² (Class I obesity); 9.7% had a BMI 35-39.9 kg/m² (Class II obesity), and 7.5% had a BMI ≥ 40 kg/m² (Class III obesity) (Flegal, Carroll, Kit, & Ogden, 2012). By the age of 44, 85% of women have had at least one pregnancy (Johnson et al., 2006) and unfortunately statistics show that 53.4% of them were overweight or obese when
becoming pregnant (Centers for Disease Control and Prevention, 2010). High maternal BMI is associated with many adverse health outcomes for the mother and fetus, which will be discussed further below. Therefore, women are encouraged to conceive at a normal BMI.

One of the goals of the *Healthy People 2020*, which is put forth by the US Department of Health and Human Services (HHS) once every decade, is that 53.4% of women should have a healthy weight (BMI 18.5-24.9 kg/m²) before pregnancy by 2020 (MICH-16.5) (Healthy People 2020, 2012). This goal is a 10% improvement from the level observed in 2007.

**B) Adverse health outcomes in obese pregnancies**

Obesity, independent of gestational weight gain (GWG), is linked to many adverse pregnancy outcomes including the health of the pregnant woman and her baby. Evidence from a substantial body of literature is sufficient to consider an obese pregnancy an “at risk” pregnancy (Baeten, Bukusi, & Lambe, 2001; Cnattingius, Bergström, Lipworth, & Kramer, 1998; Nelson et al., 2010; Sebire et al., 2001). In this literature review, selected adverse obstetric outcomes are highlighted (gestational diabetes, gestational hypertension, labor/delivery complications, and maternal and fetal deaths). The outcomes noted are seen more frequently and/or more severe pertaining to the issue of obesity during pregnancy; however, a more comprehensive overview of maternal and fetal risks of maternal obesity can be found in Figure 1.
a) **Gestational diabetes mellitus (GDM)**

During pregnancy, fasting glucose decreases and hepatic glucose production increases progressively with gestation. The increase of insulin secretion does not suppress the hepatic glucose production, which leads to a phenomenon called maternal hepatic insulin resistance (Lain & Catalano, 2007). In other words, insulin sensitivity decreases during pregnancy. The reasons for the changes in insulin sensitivity during pregnancy are uncertain, but it is believed that several hormones (i.e.: human placental lactogen (HPL), progesterone and prolactin) and cytokine (i.e.: tumor necrosis factor-α (TNF-α)) that are elevated during pregnancy could play a role (Lain & Catalano, 2007). The decrease in insulin sensitivity is further exacerbated with obesity (S. Chu, Callaghan, et al., 2007; Sebire et al., 2001; Torloni et al., 2009). A meta-analysis conducted by Chu et al., which included twenty studies on
GDM revealed that the unadjusted odds ratio (OR) of overweight, obese, and severely obese pregnant women in developing GDM were 2.14 (95% confidence interval (CI): 1.82 – 2.53), 3.56 (3.05 – 4.21), and 8.56 (5.07 – 16.04) respectively compared to normal weight pregnant women (S. Chu, Callaghan, et al., 2007). On the other hand, each year approximately 3 – 15% of pregnant women develop GDM, depending on the population and diagnostic test used (Yogev & Catalano, 2009). Multiple risk factors are associated with the development of GDM. These include ethnicity, previous history of GDM, age, parity, and family history of diabetes; however, obesity is an independent risk factor and plays a significant contribution. According to the findings of Kim et al., the percentage of GDM attributed to overweight, obesity, and extreme obesity was 46.2% (95% CI: 36.1 – 56.3) using 2003 birth certificate information from the Pregnancy Risk Assessment Monitoring System (PRAMS) (Kim et al., 2010). Gestational diabetes mellitus not only causes a “high risk” pregnancy due to the potential delivery complications, but women with GDM have an increased risk of developing type 2 diabetes mellitus later in life (Bellamy, Casas, Hingorani, & Williams, 2009), and their children are at greater risk of developing obesity later in life (Poston, Harthoorn, & Van Der Beek, 2011).

b) Gestational hypertension and pre-eclampsia

Hypertensive disorder during pregnancy is defined as new onset of hypertension after 20 weeks of gestation. If it is associated with proteinuria, this condition is called pre-eclampsia. Pre-eclampsia is diagnosed when proteinuria is shown by one or more on proteinuria test results of $\geq 300$ mg per 24-hour urine collection (Oteng-Ntim & Doyle, 2012). The risk of developing gestational hypertension or pre-eclampsia increases greatly with increasing pre-pregnancy BMI (Bhattacharya, Campbell, Liston, & Bhattacharya, 2007;
O’Brien, Ray, & Chan, 2003; Sebire et al., 2001). According to Bhattacharya et al.’s study, among 24,241 nulliparous women with singleton pregnancies delivering in Aberdeen, UK, morbidly obese women had the highest risk of pre-eclampsia (OR 7.2; 95% CI: 4.0 – 11.2), followed by moderate obese women (OR 3.1; 95% CI: 2.8 – 3.5), and overweight women (OR 1.6; 95% CI: 1.2 – 1.8) compared to women with normal BMI (Bhattacharya et al., 2007). When using waist circumference (measured between 10 to 12 weeks of gestation) as a risk marker, Sattar and colleagues also showed that among 1142 participants, those with a waist circumference greater than 80 cm, a conventional, non-pregnant waist circumference action level (Lean, Han, & Morrison, 1995), had a twofold greater risk (OR 1.8; 95% CI: 1.1 – 2.9) of developing gestational hypertension and a threefold greater risk (OR 2.7; 95% CI: 1.1 – 6.8) of developing pre-eclampsia (Sattar et al., 2001). The risk of pre-eclampsia doubled with each 5-7 kg/m² increase in pre-pregnancy BMI (O’Brien et al., 2003). Besides the immediate, adverse maternal, and neonatal outcomes, pre-eclampsia can lead to a higher risk of developing cardiovascular disease among women in later life (Bellamy, Casas, Hingorani, & Williams, 2007; Craici, Wagner, Hayman, & Garovic, 2008; O’Brien et al., 2003).

c) Labor/delivery complications

Maternal obesity is associated with increased risk of labor induction (Sebire et al., 2001; Usha Kiran, Hemmadi, Bethel, & Evans, 2005; J. Zhang, Bricker, Wray, & Quenby, 2007). For example, Usha and colleagues’ population-based observational study (n = 60,167) showed that women with BMI ≥ 30 kg/m² had an OR of 1.6 (95% CI: 1.3 – 1.9) for labor induction compared to women with BMI 20 – 30 kg/m². However, in terms of labor duration, the evidence is inconsistent. Some researchers demonstrated higher incidences of
prolonged labor and delay in the first stage of labor among the obese population, but others did not (Nuthalapaty, Rouse, & Owen, 2004; Sheiner et al., 2004; J. Zhang et al., 2007).

Interestingly, Zhang and colleagues elucidated that the high risk of delay in the first stage of labor among obese women was due to poor uterine contractility, which then leads to the increased incidence of emergency Cesarean section (C-section) (J. Zhang et al., 2007). The study demonstrated that the myometrium contracted with less force, frequency, and [Ca^{2+}] flux among the obese women compared to the normal weight women. The increased risk of C-section among the obese women in this study was consistently observed despite the adjustment for maternal age, smoking, parity and birth weight of the infants. The result of an increased incidence of C-section among obese pregnant women of Zhang et al.’s study is supported by other investigators (S Y Chu et al., 2007; Dietz, Callaghan, Morrow, & Cogswell, 2005; Sebire et al., 2001; Sheiner et al., 2004). Using data from the Pregnancy Risk Assessment Monitoring System (PRAMS), Dietz and colleagues examined the risk of C-section with excess pre-pregnancy BMI in the US population-based sample (n = 24,423 nulliparous women) (Dietz et al., 2005). The results of the study revealed that the incidence of C-section among very obese (BMI ≥ 35 kg/m²) women was as high as 42.6%. Compared to normal weight women, the estimated adjusted OR was 1.4 (95% CI: 1.0 – 1.8) for overweight women, 1.5 (95% CI: 1.1 – 2.1) for obese women, and 3.1 (95% CI: 2.3 – 4.8) for very obese women when the women delivered without any complications. The result of the US population-based sample is comparable to the increased risks found in other countries (Sheiner et al., 2004). For example, Israeli obese women who delivered between 1988 and 2002 had a 27.5% rate of undergoing C-section delivery compared to 10.8% of the normal weight women even after the exclusion of hypertensive disorders and GDM patients.
(OR = 3.2; 95% CI: 2.9 – 3.5). Currently, there is no conclusive mechanism to explain the observed independent risk factor between C-section delivery and maternal obesity. Besides poor uterine contractility among obese women, Usha and colleagues also suggested that obese women have an increased rate of large-for-gestational-age infants, which may have led to more C-section deliveries during labor. In addition, obese women also have increased fat deposition in the soft tissues of the pelvis (Usha Kiran et al., 2005). More studies are needed to investigate the causal link between obesity with C-section.

d) Maternal and fetal deaths

In a more severe case, high prepregnancy BMI has been shown to cause maternal and fetal deaths. According to the Confidential Enquiry into Maternal Deaths in the UK, 27% of the 261 deaths happening between 2006 and 2008 were related to maternal obesity (Cantwell et al., 2011). The prevalence of direct and indirect causes of mortality such as thromboembolism, pre-eclampsia, and cardiovascular disease was higher in the obese maternal population. In the United States, maternal death rates reported from California were similar compared to those reported in the UK. Thirty percent of 386 women who died in pregnancy during 2002 and 2003 were obese pregnant women (California Department of Public Health, 2011). In terms of fetal death, a meta-analysis published by Chu and colleagues reported a higher risk of stillbirths among overweight (OR 1.47; 95% CI: 1.08 – 1.94) and obese women (OR 2.07; 95% CI: 1.59 – 2.74) compared to normal weight pregnant women (Chu, Kim, et al., 2007). In a cohort study from Denmark, obese women had more than doubled risk of experiencing a stillbirth (OR 2.8; 95% CI: 1.5 – 5.3) and neonatal death (OR 2.6; 95% CI: 1.2 – 5.8) even after adjusting for maternal cigarette smoking, alcohol and caffeine intake, maternal age, height, parity, gender of the child, years
of schooling, working status, cohabitation with partners as well as hypertensive disorders and GDM (Kristensen, Vestergaard, Wisborg, Kesmodel, & Secher, 2005). The authors further elucidated that many of the stillbirth incidences in the study were caused by unexplained intrauterine death and fetoplacental dysfunction among obese women compared with normal weight women. Moreover, in a large cohort (n = 134,527) of Missouri births from 1978 to 1997, Salihu and colleagues observed a dose-dependent linear trend between BMI and the risk of stillbirth: class I obesity (adjusted hazard ratio 1.3; 95% CI: 1.2 – 1.4); class II obesity (adjusted hazard ratio 1.4; 95% CI: 1.3 – 1.6) and extreme obesity (adjusted hazard ratio 1.9; 95% CI: 1.6 – 2.1) (Salihu et al.). They further discovered that obese black mothers experienced more stillbirths than their white counterparts (adjusted hazard ratio 1.9; 95% CI: 1.7 – 2.1) compared with adjusted hazard ratio 1.4; 95% CI: 1.3 – 1.5).

**Excessive Gestational Weight Gain**

A) Overview of weight gain during pregnancy and recommendations

It is essential for women to gain weight in a normal pregnancy due to the biological processes that promote the development of new fetoplacental tissue, and maternal protein and fat tissue to support gestation and postnatal lactation. The most commonly described pattern of GWG is sigmoidal, when the majority of the weight gain during pregnancy happens in the second and early third trimesters (K. Rasmussen & Yaktine, 2009). Table 1 below shows the current 2009 GWG recommendations by the Institute of Medicine (IOM) based on a woman’s pre-pregnancy BMI (K. Rasmussen & Yaktine, 2009). These guidelines were developed after an intensive review of the available evidence. The main goals of these guidelines were to improve neonatal outcome and optimize maternal health. Different from the first published GWG recommendations in 1990, these new guidelines are based on the
WHO BMI categories (underweight: BMI < 18.5 kg/m²; normal weight: BMI 18.5 – 24.9 kg/m²; overweight: BMI 25.0 – 29.9 kg/m²; obese: BMI ≥ 30.0 kg/m²) instead of the Metropolitan Life Insurance tables (low: BMI < 19.8 kg/m²; normal: BMI 19.8 – 26.0 kg/m²; high: BMI > 26.0 – 29.0 kg/m²). Additionally, these new guidelines include a weight gain recommendation range for obese (all classes) women.

An optimum GWG happens when a woman gives birth to a healthy newborn and provides sufficient postpartum maternal fat stores to support lactation without increasing the risk of obesity (K. Rasmussen & Yaktine, 2009). The 2009 IOM GWG guidelines take into account the risk of giving birth to a small-for-gestational-age (SGA) (birth weight ≤ 10th percentile) or large-for-gestational-age (LGA) (birth weight ≥ 90th percentile) baby; therefore, birth weight played a pivotal role in developing the guidelines. In general, obese women are advised to gain less weight than non-obese women. The weight gain recommendation of 5 to 9 kg (11 to 20 lbs.) for obese women allows the growth of the fetus without much gain in maternal tissue, especially maternal fat. However, the 2009 IOM GWG guidelines do not further stratify the obese population to class I, II or III due to the limited studies to guide the recommendations.

Some studies provided evidence of no harm to the mother and fetus when very obese women actually lost weight during pregnancy (Kiel, Dodson, Artal, Boehmer, & Leet, 2007; Nohr et al., 2008; Oken, Kleinman, Belfort, Hammitt, & Gillman, 2009). For example, a cohort study using birth certificate data from 120,251 obese women in Missouri argued that the optimal GWG for class I and II obese women should be 4.6 to 11.4 kg, and 0 to 4.1 kg respectively; while, class III obese women should be advised to lose 0 to 4.1 kg instead of gaining weight during pregnancy. These recommendations were developed by taking into
account the risk for pre-eclampsia, C-section, LGA babies, and SGA babies among women in the study (Kiel et al., 2007). Another study conducted by Hinkle and colleagues supported the above findings. Compared to those who gained according to the recommendation guidelines of 5 to 9 kg among the obese class II and III women, a GWG of -4.9 to 4.9 kg did not significantly increase the risk of giving birth to SGA infants, but rather decreased the risk of LGA infants (Hinkle, Sharma, & Dietz, 2010).

Gestational weight gain is influenced by changes in maternal physiology, maternal metabolism and placental metabolism. The components of GWG and the proximal percent of each of these components include 27% of fetus, 20% of placenta, amniotic fluid and uterus, 3% of breast weight, 23% blood volume and extravascular fluid, and 27% maternal fat stores (Herring, Rose, Skouteris, & Oken, 2012). Weight gain at the beginning of pregnancy closely reflects maternal fat gain, while weight gain later on in pregnancy reflects fetal components (Kleinman et al., 2007; Muscati, Gray-Donald, & Koski, 1996). Therefore, in alignment with the IOM guidelines, underweight and normal weight women are advised to deposit fat in early- and mid-pregnancy stages as a caloric reserve for late pregnancy and lactation; however, women entering pregnancy overweight or obese are not required to have this extra caloric reserve (Herring et al., 2012). Lederman and colleagues reported that fat accumulation is positively correlated with GWG \( (r = 0.81, p < 0.0001) \). In this study, the authors showed that fat mass gain among underweight women who gained according to the recommendation was the highest \((4.8 \pm 3.8 \text{ kg})\), followed by normal weight \((3.9 \pm 3.7 \text{ kg})\), overweight \((2.8 \pm 5.4 \text{ kg})\) and obese \((0.2 \pm 5.0 \text{ kg})\) women (Lederman et al., 1997). Some studies even demonstrated that maternal fat gain had no benefits for fetal growth among
normal or overweight women (Langhoff-Roos, Lindmark, & Gebre-Medhin, 1987; Lawrence, McKillop, & Durnin, 1991).

Additionally, since infant birth weight is associated with gestational weight gain during the second and third trimester (Lawton, Mason, Kelly, Ramsay, & Morewood, 1988; Lertbunnaphong, Talungjit, & Titapant, 2012), Muscati and colleagues argued that timing of GWG was as important as the total amount of weight gain during pregnancy (Muscati et al., 1996). They provided evidence that early GWG (≤ 20 weeks) was a strong predictor of six-week post-partum weight retention. The rate of weight gain for the first half of pregnancy should be carefully monitored among overweight women to avoid excessive fat deposition. As a result, they concluded that in order to promote fetal growth and reduce the risk of substantial post-partum weight retention, it was more advantageous for women, especially overweight women, to delay their weight gain until late pregnancy. Lederman and colleagues also showed that women who gained more than recommended amounts also gained significantly more fat mass. The results of Lederman and colleagues are supported by more recent data, which demonstrated that weight gain in early pregnancy reflects maternal fat deposition and could potentially lead to offspring obesity (Fraser et al., 2010; Huda, Brodie, & Sattar, 2010). In summary, excessive GWG should be avoided throughout pregnancy for the health of the mother and fetus.
Table 1: Institute of Medicine (2009) Recommendations for Total and Rate of Weight Gain during Pregnancy, by Pre-pregnancy BMI.

<table>
<thead>
<tr>
<th>Pre-pregnancy BMI</th>
<th>Total Weight Gain</th>
<th>Rates of Weight Gain 2nd and 3rd Trimester*</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Range in kg</td>
<td>Range in lbs</td>
</tr>
<tr>
<td>Underweight (&lt; 18.5 kg/m²)</td>
<td>12.5 - 18</td>
<td>28 - 40</td>
</tr>
<tr>
<td>Normal weight (18.5 - 24.9 kg/m²)</td>
<td>11.5 - 16</td>
<td>25 - 35</td>
</tr>
<tr>
<td>Overweight (25.0 - 29.9 kg/m²)</td>
<td>7 - 11.5</td>
<td>15 - 25</td>
</tr>
<tr>
<td>Obese (≥ 30.0 kg/m²)</td>
<td>5 - 9</td>
<td>11 - 20</td>
</tr>
</tbody>
</table>

* Calculations assume a 0.5 - 2 kg (1.1 - 4.4 lbs) weight gain in the first trimester
Adapted from (K. Rasmussen & Yaktine, 2009).

B) Adverse health outcomes of excessive GWG

Excessive GWG is another concern in the field of maternal and child health. The latest data shows that 48% of pregnant women gained more weight than recommended. The majority of the women who gained excessively during gestation were women who were overweight or obese before entering to pregnancy (Centers for Disease Control and Prevention, 2010). Excessive GWG can be particularly concerning for overweight and obese women due to their already increased risk for adverse pregnancy outcomes. Evidence shows that women who gain an appropriate amount of weight during pregnancy are likely to have good obstetric and neonatal outcomes. They also have less concern with the amount of weight that they need to lose in the postpartum period (Siega-Riz et al., 2009). In the following section, a selection of the main adverse pregnancy outcomes pertaining to excessive GWG will be discussed. Adverse outcomes for the child such as macrosomia (LGA infant), and increased risk for later child obesity will be addressed under the topic of “Fetal Origin of Obesity”.
**a) Gestational diabetes mellitus (GDM)**

In general, the evidence of a positive relationship between excessive GWG and GDM is inconclusive. For example, when Hedderson and colleagues sought to determine the relationship between rate of GWG and risk of GDM (n = 1134), they found that women with a rate of weight gain between 0.27 – 0.40 kg/week and > 0.40 kg/week week had an odds ratio of 1.43 (95% CI: 0.96 – 2.14) and 1.74 (95% CI: 1.16 – 2.60) to develop GDM compared to women in the rate of weight gain < 0.27 kg/week (Hedderson, Gunderson, & Ferrara, 2010). In contrast, data from the Danish National Birth Cohort (n = 60,892) revealed that GDM was significantly associated with low weight gain (<10 kg compared to 10 – 15 kg) instead of high weight gain during pregnancy (adjusted OR 2.3; 95% CI: 1.9, 2.8) (Nohr et al., 2008). Additionally, when Herring and colleagues examined women (n = 1960) in Project Viva, a pre-birth cohort in eastern Massachusetts, they found that women in the highest quartile of weight gain had increased odds of impaired glucose tolerance (adjusted OR 2.54; 95% CI: 1.25 – 5.15), but not GDM (adjusted OR 0.93; 95% CI: 0.50 – 1.70) compared with women who gained at the lowest quartile (Herring et al., 2009).

**b) Gestational hypertension and pre-eclampsia**

There appears to be a strong link between excessive GWG and the development of pre-eclampsia. In the Danish National Birth Cohort (n = 60,892), women who gained 16 – 19 kg and ≥ 20 kg had an adjusted OR of 1.6 (95% CI: 1.3 – 1.8) and 2.8 (95% CI: 2.4 – 3.2) respectively to develop pre-eclampsia during pregnancy compared to women who only gained 10 – 15 kg (Nohr et al., 2008). When examining the effects of low and high GWG in different maternal BMI classes, Cedergen found that obese women with low GWG had only half of the risk to develop pre-eclampsia compared to those with high GWG (adjusted OR
0.52; 95% CI: 0.42 – 0.62). The study also showed that normal and overweight women had twice the risk of developing pre-eclampsia with excessive GWG (Cedergren, 2006). Cedergren’s work was supported by Brennand et al., who found that obese women with low, acceptable and high weight gain had a prevalence of 3.7%, 6.3% and 14.9% respectively to develop pre-eclampsia during pregnancy (Brennand, Dannenbaum, & Willows, 2005). This positive relationship between excessive GWG and risk of pre-eclampsia and hypertension disorder holds true for other ethnicities, such as the Latino population. Among a group of obese (BMI > 29 kg/m²) Latino women (n = 1231), Fortner et al. found that women in the study who gained excessively had a 3-fold risk of hypertension disorder (95% CI: 1.1 – 7.2) and a 4-fold risk of pre-eclampsia (95% CI: 1.2 – 14.5) compared to women who gained according to the 1990 IOM guidelines (Fortner, Pekow, Solomon, Markenson, & Chasan-Taber, 2009).

c) Post-partum weight retention

Excessive GWG is positively associated with postpartum weight retention (Gunderson, 2009; Nelson et al., 2010; Yogev & Catalano, 2009), and is a strong predictor of long-term overweight and obesity beyond pregnancy (Susan Y Chu, Callaghan, Bish, & D’Angelo, 2009; Davis, Zyzanski, Olson, Stange, & Horwitz, 2009). It also leads to higher weight status for future pregnancies (Gunderson, 2009). Nohr and colleagues reported that around 12% of normal-weight, overweight and obese class I women moved up one BMI category with a GWG of 16 – 19 kg, but this percentage increased to approximately 25% when these women gained ≥ 20 kg (Nohr et al., 2008). In Gunderson and colleagues’ study of 1300 women who delivered at the University of California, San Francisco (UCSF) hospital between 1980 and 1990 showed that normal weight (BMI ≤ 26 kg/m²) women who
gained above the 1990 IOM recommendations had a 2.5 to 3-fold higher risk of becoming overweight at their following pregnancy (Gunderson, Abrams, & Selvin, 2000).

In terms of the risk of long-term obesity, Rooney and Schauberger demonstrated that women who gained less than the 1990 IOM guidelines were 4.1 kg heavier between 5 to 10 years later (at follow-up visit), while those who gained according to the guidelines and exceeded the guidelines were 6.5 kg and 8.4 kg heavier respectively ($p = 0.01$). This study also showed that women who lost all gestational weight by 6-months postpartum were lighter (only 2.4 kg heavier at follow-up) than women who retained some gestational weight at 6-months post-partum (8.3 kg heavier) (Rooney & Schauberger, 2002). In summary, excessive GWG contributes to obesity in women, which may increase the overall health care burden. Therefore, interventions are needed to help pregnant women reach their targeted weight range, especially women who are overweight and obese before they conceive.

**Fetal Origins of Obesity**

**A) The concept of Developmental Origins of Health and Disease (DOHaD) hypothesis**

In the past, it was thought that chronic diseases such as coronary heart disease, diabetes, cancer, asthma, and obesity were the results of genetic inheritance and/or unhealthy lifestyles; however, a new paradigm to better understand these diseases has emerged in recent years. Mounting evidence reveals that one’s exposure to the intrauterine environment, and environmental exposure during infancy may play a pivotal role in the development and progression of chronic diseases (Barker, 2007; Gillman, 2005; Oken & Gillman, 2003; Wadhwa, Buss, Entringer, & Swanson, 2009). This new paradigm is referred to as the “Developmental Origins of Health and Disease (DOHaD)” or also known as “Barker’s hypothesis”. This hypothesis emerged almost 25 years ago, which evolved from a
series of epidemiological studies of infant and adult mortality by Barker and colleagues (Barker et al., 1993; Barker, Winter, Osmond, Margetts, & Simmonds, 1989; Barker & Osmond, 1986). Their studies provided the foundation of the relationship between restricted fetal growth and small size at birth due to nutrient deficiency in utero (Barker, 2007). This “intrauterine stress” became an agent to permanently alter the structure and function of fetal organ systems, which in turn leads to coronary heart disease and stroke in adult life. This process is also called fetal programming, which means the gene expression of a certain organ is altered when it gets exposed to a variety of environmental stimuli, such as stress, poor nutrition and/or drugs. This alteration is permanent and usually it leads to disease development (Wadhwa et al., 2009). Barker et al. showed that for every one kilogram decrease in birth weight there was a 14% increased risk of mortality by 75 years of age (Barker et al., 1989). Low birth weight is also associated with other risk factors, for example hypertension, insulin resistance and stroke (Cota & Allen, 2010).

Another aspect of the DOHaD hypothesis is the concept of compensatory growth. Compensatory growth is also called “catch-up” growth, which describes the phenomenon of a period of under-nutrition in the utero environment followed by a rapid weight gain during early development. This catch-up period may lead to disproportionally high fat mass to fat-free mass, which has been associated with adverse health outcomes. Barker and colleagues’ study of coronary events among the 8760 people born in Helsinki from 1934 – 1944 showed that those who had below average birth weight and BMI at 2 years of age, but rapidly increased their BMI from 2 to 11 years of age, had significantly higher coronary risk factors. Therefore, they concluded that catch-up growth further exacerbated the risk of developing cardiovascular disease in later life (Barker, Osmond, Forsén, Kajantie, & Eriksson, 2005).
B) DOHaD hypothesis in obesity

Many investigators have recently turned to the DOHaD hypothesis to gain a better understanding of the obesity epidemic (Adamo et al., 2012; Dabelea & Crume, 2011; Oken & Gillman, 2003). When the relationship between birth weight and obesity later in life was studied, the researchers found “trouble on both ends of the birth weight spectrum,” as mentioned by Oken and Gillman (Oken & Gillman, 2003). Fetal origins of obesity is related to both low and high birth weight, which suggests the presence of two pathogenesis of obesity.

a) Association of birth weight and obesity risk factors

At one end of the spectrum, low birth weight ($\leq 2500$ g) is associated with central or truncal obesity (M. Barker, Robinson, Osmond, & Barker, 1997; Law, Barker, Osmond, Fall, & Simmonds, 1992), insulin resistance (Bavdekar et al., 1999; McKeigue, Lithell, & Leon, 1998; Mi et al., 2000), and metabolic syndrome (D J P Barker, Hales, et al., 1993; Valdez, Athens, Thompson, Bradshaw, & Stern, 1994; Yarbrough, Barrett-Connor, Kritz-Silverstein, & Wingard, 1998). In a study examining the ratio of waist to hip circumference, the authors found that the waist to hip ratio of men (n = 845) who were born during 1920 – 30 at Hertfordshire (UK) and men (n = 239) who were born during 1935 – 43 at Preston (UK) was inversely related to birth weight after controlling for gestational length. Additionally, they also observed a similar trend when weight at one year of age was examined after controlling for adult height, alcohol consumption, smoking, social class, and age. Therefore, the authors concluded that adverse conditions or growth failure in uterine and during infancy may be the main culprit of the detrimental abdominal fat storage detected in this study (Law et al., 1992).
There is no exception when it comes to the relationship of birth weight to adolescent female abdominal fat storage. Again, in one of Barker and colleagues’ studies they found girls who had the smallest birth weight (≤ 3000 g) were the fattest at the time of measurement (mean age = 15.6 year old, total n = 216). For every kilogram decrease in birth weight, the subcapular to triceps skinfold ratio increased by 9% in girls whose BMI was above the median (21 kg/m²) and 27% in those whose BMI was over 25 kg/m². As a result, there appeared to be a tendency to store fat centrally that seemed to be programmed during fetal growth, especially for those who were overweight (M. Barker et al., 1997). It is well documented that central fat deposition is an independent risk factor of insulin resistance, non-insulin dependent diabetes and metabolic syndrome (Lévy-Marchal & Czernichow, 2006). Therefore, birth weight has an inverse relationship with the diseases aforementioned (Philips, 1998). McKeigue and colleagues reported a positive monotonic relation of insulin sensitivity with birth weight in males at full term. This relationship was the strongest in those who were overweight at age 70 (McKeigue et al., 1998). In a population-based sample of older women, both the prevalence (12 vs. 4.3%) and the risk of developing metabolic syndrome (OR 2.41; 95% CI: 1.06 – 5.51) increased in women who had the lowest birth weight tertile (2.5 – 6.8 lb, mean 5.5 lb) compared to the women who had the highest birth weight tertile (8.1 – 13.0 lb, mean 9.4) (Yarbrough et al., 1998).

Besides low birth weight, catch-up growth could potentially play a part in the development of metabolic syndrome, too. Fagerberg and colleagues have studied the combination of low birth weight and catch-up growth in predicting the occurrence of metabolic syndrome in late middle aged men (Fagerberg, Bondjers, & Nilsson, 2004). They found that among all of the participants (n = 396), those who gained the most weight from
birth to 18 years of age also had the highest incidence of metabolic syndrome at 58 years ($p = 0.008$). The correlations between weight ratio from birth to age 18 and metabolic syndrome at 58 were: BMI ($r = 0.24, p < 0.001$), WHR (waist-to-hip ratio) ($r = 0.24, p < 0.001$), diastolic blood pressure ($r = 0.13, p < 0.05$), insulin ($r = 0.14, p < 0.01$), triglycerides ($r = 0.10, p < 0.05$), HDL cholesterol ($r = -0.13, p < 0.01$) and LDL particle size ($r = -0.17, p < 0.05$) (Fagerberg et al., 2004). The relationship of low birth weight and insulin resistance syndrome was also observed in some other developing countries such as India (Bavdekar et al., 1999) and China (Mi et al., 2000) where low birth weight was particularly common.

On the other end of the spectrum, studies have demonstrated that higher birth weight is associated with higher attained BMI later in life (Curhan et al., 1996; Gillman, Rifas-Shiman, Berkey, Field, & Colditz, 2003; Parsons, Power, Logan, & Summerbell, 1999; Rasmussen & Johansson, 1998; Sørensen et al., 1997). This relationship is relatively robust even after controlling for potential confounders. For example, in the Nurses’ Health Study I (n = 71,100 women) and II (n = 92,940) women who weighed more than 10 lbs at birth compared to those who weighed between 7.1 and 8.5 lbs had an OR of 1.62 (95% CI: 1.38 – 1.90) of being obese in midlife after controlling for maternal weight (Curhan et al., 1996). In the U.S. Growing Up Today Study, a cohort study of diet, activity, and growth of girls (n = 7981) and boys (n = 6900), the investigators found that each 1-kg increment increase in birth weight among full term infants was associated with an approximate 50% increased risk of being overweight at ages 9-14 years. The risk reduced to approximately 30% after adjusting for physical activity, television watching, energy intake, breastfeeding duration, and maternal BMI (Gillman, Rifas-Shiman, Berkey, Field, & Colditz, 2003).
Therefore, there is a direct relationship between birth weight and BMI in childhood and adulthood, but an inverse relationship between low birth weight and central adiposity, insulin resistance, and metabolic syndrome. These relationships can be described as U- or J-shaped relationships where the extremes of both ends of the birth weight spectrum possess obesity risk factors later in life (Oken & Gillman, 2003). Because a large number of reproductive-age women in Western societies or developed countries (i.e.: America) struggle with the risk of giving birth to LGA infants rather than the risk of giving birth to SGA infants due to the plentiful food supply and obesogenic environment (Dabelea & Crume, 2011), the focus of my dissertation will be mainly to discuss the potential causes and mechanisms that lead to giving birth to LGA infants and how it could cause obesity later in life in developed countries.

b) Evidences of the causes: maternal obesity and excessive GWG

Maternal obesity and GWG are two of the main causes of giving birth to a LGA infants in most Western countries (Adamo et al., 2012; Dabelea & Crume, 2011; Nelson et al., 2010; Oken, 2009b). When Hull and colleagues studied the impact of maternal BMI on neonatal body composition, they found that the newborns (n = 77) of overweight and obese women (BMI ≥ 25 kg/m²) had higher percent fat (12.5 ± 4.2% vs. 13.6 ± 4.3%; \(p \leq 0.0001\)), fat mass (414.1 ± 264.2 vs. 448.3 ± 262.2; \(p \leq 0.05\)), and fat-free mass (3310.5 ± 344.6 vs. 3162.2 ± 343.4; \(p \leq 0.05\)) compared to normal-weight women when the neonatal body compositions were measured using the PEA POD system (Hull, Dinger, Knehans, Thompson, & Fields, 2008). The findings of Hull et al. have been supported by other studies (Harvey et al., 2007; Neggers, Goldenberg, Cliver, Hoffman, & Cutter, 1995; Sewell,
Huston-Presley, Super, & Catalano, 2006; Shields, Knight, Powell, Hattersley, & Wright, 2006).

There is also much evidence suggests that the association of maternal obesity and offspring obesity will persist through childhood, adolescence and adulthood (C. Li, Goran, Kaur, Nollen, & Ahluwalia, 2007; L. Li, Law, Conte, & Power, 2009; Salsberry & Reagan, 2005; Robert C Whitaker, Wright, Pepe, Seidel, & Dietz, 1997). For example, when Whitaker and colleagues studied the role of maternal obesity in predicting obesity among preschool-aged children, they found that children ages 2 to 4 (n = 8494) who were born to obese mothers had more than twice the likelihood of being obese. By 4 years of age, one in four children of obese mothers were obese, compared to less than one in ten for normal weight mothers (R C Whitaker, 2004). Li and colleagues’ study of 2626 children in the National Longitudinal Study of Youth (NLSY) between ages 2 to 14 provided a consistent result. In this study, the authors noted that children of obese women were at a greater risk of becoming overweight (OR 4.1; 95% CI: 2.6 – 6.4) even after the adjustment of potential confounders (i.e.: parity, gestational age, breastfeeding) (C. Li et al., 2005). Data from other developed countries, such as Finland (Laitinen, Power, & Järvelin, 2001), England (Reilly et al., 2005), Sweden (Koupil & Toivanen, 2008), and Australia (O’Callaghan, Williams, Andersen, Bor, & Najman, 1997) also demonstrated a similar association.

When discussing the relationship between GWG and offspring obesity, according to some of the most recent reviews (Adamo et al., 2012; Nelson et al., 2010; Poston, 2012), many epidemiological and observational data support an association between the two. One particular landmark study in the United States is Project Viva, which showed that excessive GWG is directly associated with a child being overweight at age 3 (OR 1.30; 95% CI: 1.04 –
1.62 for each 5 kg of GWG) after adjusting for sociodemographic factors, breastfeeding duration, glucose tolerance, and gestation length (Oken et al., 2007). Another big cohort study, the US Collaborative Perinatal Project (n = 10,226), supported the findings of Oken et al (Wrotniak, Shults, Butts, & Stettler, 2008). In this study, there was a 3% increase in the rate of being overweight among offspring at age 7 for every 1 kg of GWG (OR 1.03; 95% CI: 1.02 – 1.05). When looking at the pattern of weight gain across the gestational period by using the Avon Longitudinal Study of Parents and Children (ALSPAC), a UK-based prospective pregnancy cohort (n = ~ 12,500), Fraser and colleagues reported a positive relationship between GWG in early pregnancy (0 to 14 weeks) and offspring adiposity at age 9 years in all data; while GWG was only related with offspring adiposity in women who gained > 500 g/wk between 14 and 36 weeks (Fraser et al., 2010). Through these findings, the authors concluded that women should avoid excessive weight gain in early pregnancy, as this early weight gain may cause the GWG and offspring adiposity relationship.

Generally speaking, women who are overweight or obese prior to conceiving should avoid excessive GWG at all costs. Studies have demonstrated the significantly increased association between excessive GWG and offspring obesity among overweight and obese women compared to normal weight women (Z. M. Ferraro et al., 2012; Guihard-Costa, Papiernik, & Kolb, 2004; Hull et al., 2011). For example, when GWG was classified as appropriate or excessive according to the 2009 IOM guidelines within each of the pre-pregnancy BMI categories, Hull and colleagues found that newborns of women in the overweight pre-pregnancy BMI category had a significantly higher percent fat mass ($p = 0.001$) when the mothers gained excessively (infant fat mass = 484.4 ± 28.8 g) compared to those who gained appropriately (infant fat mass = 303.6 ± 46.1 g). The differences were not
significant among the obese group due to the already relatively high fat mass of the newborns (infant fat mass of appropriate group = 472.9 ± 56.0 g vs. infant fat mass of excessive group = 486.4 ± 33.5 g) (Hull et al., 2011). The combination of maternal obesity and excessive GWG appear to cause adverse health outcomes both to the mother and fetus.

c) Mechanisms

Evidence supporting the association between maternal obesity, excessive gestational weight gain and offspring obesity has been primarily attributed to genetics, and familial socioeconomic and lifestyle factors. However, in recent years, investigators have considered whether the intrauterine environment of obese women and of those with excessive gestational weight gain, could potentially program long-term offspring obesity. BMI or weight of children correlated more strongly with maternal BMI or weight than paternal BMI or weight, as shown by epidemiological and observational studies, which further supports the role of the intrauterine environment on downstream obesity development (Danielzik, Langnase, Mast, Spethmann, & Müller, 2002; Lawlor et al., 2007; C. Li et al., 2007; Moschonis, Grammatikaki, & Manios, 2008; Reilly et al., 2005; Q. Wu & Suzuki, 2006). In the words of Barker, ‘The womb may be more important than the home’ (Barker, 1990).

In order to evaluate the contribution of the intrauterine environment to the risk of developing obesity in childhood and beyond, animal and human studies have been conducted to provide supporting evidence for this potential etiology of obesity. For example, by using an enteral nutrition-based over-feeding obese rat model, Shankar and colleagues were able to show that the offspring of rats who were exposed to maternal obesity in utero were programmed to be obese later in life when they were fed a high-fat diet (Shankar et al., 2008). Compared to the offspring of lean dams, offspring of obese dams had significantly
higher weight gain, as well as higher total, visceral, and subcutaneous percent fat mass when they were given the same high-fat diet ($p < 0.005$). Additionally, offspring of obese dams had $\sim 1.6$-fold greater percent fat ratio compared to offspring of lean dams when they consumed the same control diet (normal diet) ($p < 0.05$).

In terms of human studies, some of the best models to examine the role of the intrauterine environment on offspring obesity are those studies on pre- and post-bariatric surgery patients. Thus far, both Kral et al. and Smith et al. have done elegant work comparing siblings who were born before and after the mother’s surgery, since siblings carry similar genes and share a similar postnatal environment (Kral et al., 2006; Smith et al., 2009). In Kral and colleagues’ study, the siblings (aged 2 to 18 years old) who were born after substantial maternal weight loss due to biliopancreatic bypass surgery, had a 52% and 45.1% reduction in the prevalence of obesity and severe obesity, respectively (Kral et al., 2006). The results of Kral et al.’s study were later supported by Smith and colleagues, who also examined cardiometabolic risk factors of their participants ($n = 54$ before surgical weight loss; $n = 57$ after surgical weight loss) (Smith et al., 2009). Besides the lower prevalence of macrosomia (LGA infant) and severe obesity among the post-surgery siblings, the Smith et al., also reported that children who were born after maternal surgical weight loss had greater insulin sensitivity, improved lipid profiles, lower C-reactive protein (indication of inflammation), decreased leptin (adipose-derived hormone), and increased ghrelin (circulating hunger hormone), compared with their siblings who were born before the surgery.

In an innovative way, Lawlor et al. also conducted a sibling study to examine the role of the intrauterine environment on offspring obesity without using data from bariatric
patients (Lawlor, Lichtenstein, Fraser, & Langstrom, 2011). Lawlor et al. compared within-sibling associations to non-sibling associations to examine the relative strength of a shared intrauterine environment and/or of shared familial (genetic and lifestyle) risk factors on offspring BMI at age 18 years (n = 146,894 individuals from 136,050 families). The results showed that in women with normal pre-pregnancy BMI, there was no association between maternal GWG and greater offspring BMI, within-siblings; however, a positive association was found between maternal GWG and offspring BMI within-siblings in overweight/obese mothers. Therefore, the authors concluded that among normal weight women, the positive association between GWG and offspring BMI is mainly due to shared familial risk factors, while in overweight/obese women this association could be caused by both intrauterine environment and shared familial risk factors. By and large, evidence to support the role of the intrauterine environment on intergenerational transmission of obesity has slowly emerged in the past decade. However, the question yet to be answered is what are the potential underlying mechanisms in the intrauterine environment of obese women and/or women who gain excessive weight during gestation and ultimately causing the persistent influence on offspring obesity? The mechanisms responsible for these effects remain unknown, but potential pathways have been areas of intense research, and these include the developmental over-nutrition hypothesis and epigenetics.

i) The developmental over-nutrition hypothesis

Through studying the Dutch famine (1944 – 45), researchers started to realize the important role of prenatal and early post-natal nutrition in offspring obesity (Ravelli, Stein, & Susser, 1976). In this study, the investigators observed that males exposed to nutritional deprivation in utero during the first half of pregnancy experienced higher adult obesity rates
(ρ < 0.0005). The proposed mechanism was that under-nutrition during the critical early period of development in the womb affected the differentiation of hypothalamic centers (function to regulate food intake and growth); therefore, when food availability increased later in life, this then caused an accumulation of excess fat in a predetermined maximum size of an individual body.

On the contrary, fetal over-nutrition is equally detrimental to offspring development. The fetal over-nutrition hypothesis, or fetal teratogenesis, was first proposed by Pederson in the 1950s (Pederson, 1954). In his study, Pederson observed a greater delivery of glucose from diabetic mothers to their fetuses, which directly (fetal glucose consumption) or indirectly (fetal hyperinsulinemia) caused excessive growth in the developing fetuses. Maternal glucose can freely transfer to the fetus, but maternal insulin does not cross the placenta, which leads to fetal pancreatic release of insulin in response to the glucose load. Excessive production of insulin acts as fetal growth hormone, which causes growth and adiposity. Therefore, women who have GDM are at higher risk of giving birth to LGA infants (Dabelea & Crume, 2011). Besides the risk at birth, these infants are also at a higher risk of being overweight and obese during childhood and adolescence (Chandler-Laney, Bush, Rouse, Mancuso, & Gower, 2011; M W Gillman et al., 2003; Hillier et al., 2007), having higher blood pressure (Wright et al., 2009), and becoming diabetic later in life (Fetita, Sobngwi, Serradas, Calvo, & Gautier, 2006).

Even without being diagnosed with GDM, many studies have demonstrated a continuous, linear relationship between maternal hyperglycemia with macrosomia and other adverse health outcomes (Hill, Krishnaveni, Annamma, Leary, & Fall, 2005; The HAPO Study Cooperative Research Group, 2008; Yoge, Langer, Xenakis, & Rose, 2005). For
example, in the multicenter, multinational, Hyperglycemia and Adverse Pregnancy Outcomes (HAPO) study, the investigators observed a strong relationship between maternal glucose levels and birth weight, cord-blood serum C-peptide (indication of insulin levels), and neonatal adiposity among the 23,316 non-diabetic participants (The HAPO Study Cooperative Research Group, 2008). This study has provided some of the most comprehensive evidence for the Pedersen Hypothesis.

In more recent decades, the developmental over-nutrition hypothesis has been broadened to include other fuels, such as free fatty acids, ketone bodies, and amino acids, which could contribute to fetal hyperinsulinemia, and therefore fetal over-growth (Freinkel, 1980). In 1985, it was reported that placental lipoprotein lipase could hydrolyze maternal triglycerides to free fatty acids. These free fatty acids were able to cross the placenta and incorporate into fetal lipids (Knopp, Bergelin, Wahl, & Walden, 1985). As a result, several human studies have provided evidence for the relationship between maternal lipids and fetal adiposity (Di Cianni et al., 2005; Kitajima et al., 2001; Knopp et al., 1985).

Overweight/obese women and/or women with excessive GWG may possess the same physiological condition, which is comparable to women with GDM or hyperglycemia, where plasma levels of glucose and other nutrients are elevated. Consequently, in a review on the role of the prenatal environment in the development of obesity, Whitaker and Dietz claimed that diabetes, obesity and excess GWG can independently influence the transfer of metabolic substrates to the fetus due to the high circulating concentration of substrates (Robert C Whitaker & Dietz, 1998). The substrates, after crossing the placenta, could then directly or indirectly affect the fetus’ development by increasing insulin secretion.
Similar to maternal under-nutrition, maternal over-nutrition could affect hypothalamic cell proliferation. Hypothalamic maturation occurs during the intrauterine period of human development, with the majority taking place during early gestation (Koutcherov, Mai, Ashwell, & Paxinos, 2002). Maternal obesity or over-nutrition could influence the hypothalamic expression of appetite regulators (Bouret, 2012). The two most commonly studied appetite regulators are the neuropeptide Y (NPY), which is an appetite stimulator, and the pro-opiomelanocortin (POMC), which is an appetite suppressor. A study by Chen and colleagues showed that offspring from obese rats had greater levels of hyperphagia, adiposity, hyperlipidemia, and glucose intolerance (Chen, Simar, & Morris, 2009). When hypothalamic appetite regulators were measured, there was increased hypothalamic NPY signaling in adult offspring, which explained the increased drive to eat in perinatally malprogrammed rats. In short, disruption of the hypothalamic maturation during gestation could lead to long-term dysfunction of energy homeostasis.

### ii) Epigenetics

Epigenetics is the study of heritable changes in gene expression caused by other processes, such as DNA methylation and histone modifications, without altering the DNA sequence. The rapid increase in obesity rates worldwide cannot be explained by changes in the genome over a short period of time; therefore, researchers are examining the influences of environmental factors on gene expression. Gestation is a vulnerable and critical period for epigenetic modifications to occur, due to the high rates of DNA synthesis and methylation (Wadhwa et al., 2009). As a result, more recently, studies have suggested that epigenetic modifications that may happen in utero could be the explanation for the relationship between maternal obesity and excessive GWG and long-term offspring obesity (Fall, 2012;
Godfrey et al., 2011; Wadhwa et al., 2009). Thus far, animal models have been used extensively to understand this relationship, especially in the area of maternal over-nutrition relating to genes involved in the regulation of energy homeostasis (Q. Wu & Suzuki, 2006). However, human studies focused on the influence of the intrauterine environment on epigenetic modifications are limited. One study has demonstrated the correlation between maternal hyperglycemia to placental leptin DNA methylation levels (Bouchard et al., 2010). Another human study conducted by Godfrey et al. found that higher methylation of retinoid X receptor-α (RXR) chr9 was associated with higher neonatal adiposity, which has an inverse relationship with maternal carbohydrate intake in early pregnancy (Godfrey et al., 2011). Therefore, they concluded that diet in early pregnancy could influence a child’s adiposity through the methylation of RXR gene. The field of epigenetics on DOHaD hypothesis is an emerging research area. More human studies are yet to be conducted to support this mechanism on the development of offspring obesity.

**Preventing Pediatric Obesity during Pregnancy**

The DOHaD hypothesis elucidates how an unfavorable intrauterine environment due to maternal obesity and excessive GWG increases the risk of obesity in the offspring. These two factors cause a perpetuating “vicious cycle” of obesity, where obese women or women who gain excess gestational weight have a higher risk of giving birth to LGA infants, who then, years later, can become obese adults entering into their own pregnancies (Oken, 2009b). Therefore, obesity prevention by targeting pregnancy could be a promising starting point. Pregnancy is a naturally occurring life transition that often makes women concerned about the well-being of their babies and many women desire to become role models for their new children (Phelan, 2010). This can make pregnancy a “teachable moment”. As a result,
pregnancy may be an ideal time to introduce lifestyle intervention as women are motivated to adopt healthy behaviors for the sake of their children. Weight gain and obesity occur when energy intake exceeds energy expenditure, which results in energy imbalance. It is well-established that healthy eating habits and regular physical activity are two modifiable targets in preventing weight gain at all ages and among all populations. Thus, these two behaviors should be encouraged among pregnant women, too. Due to the nature of the proposed project, the following dissertation will be focused on maternal physical activity; however, an overview of diet during pregnancy will be discussed.

A) **Maternal physical activity (PA)**

a) **Maternal PA recommendations, trends and types**

A positive relationship between PA and health and wellness across an individual’s lifespan as well as its significant impact on the public health is widely known. Regular PA is shown to reduce the risk of cardiovascular disease, stroke, type 2 diabetes, cancer, obesity, depression and anxiety (“Physical activity guidelines advisory committee report, 2008. To the Secretary of Health and Human Services. Part A: executive summary,” 2009). In more recent years, PA during pregnancy has been viewed as an important part of reproductive health. Pregnant women are encouraged to have an active lifestyle, which has replaced the traditional view that pregnant women should engage in limited exercise (Downs et al., 2012). Maternal PA is considered safe when performed by healthy pregnant women without any prenatal complications. There is little, if any, evidence for harmful effects of prenatal PA on maternal and child health outcomes as examined in many published reviews (Morris & Johnson, 2005; Mudd, Owe, Mottola, & Pivarnik, 2013; Pivarnik et al., 2006).
According to the American College of Obstetrics and Gynecology (ACOG) 2002 guidelines, in the absence of either medical or obstetric complications, pregnant women can accumulate 30 minutes or more of moderate-intensity exercise on most, if not, all days of the week (ACOG Committee Obstetric Practice, 2002). Later, when the U.S. Department of Health and Human Services (DHHS) issued the first-ever physical activity guidelines for Americans in 2008, they included the recommendations for the pregnant population who are healthy and without medical complications (“Physical activity guidelines advisory committee report, 2008. To the Secretary of Health and Human Services. Part A: executive summary,” 2009). Two key guidelines from the U.S. DHHS are 1. Pregnant women who are not already active should get at least 150 minutes of moderate-intensity aerobic activity per week, preferably spread throughout the week; 2. Pregnant women who are highly active prior to conception can continue their activities, but they need to consult with their health care provider and adjust their activities as the pregnancy progresses.

When examining the prevalence of PA participation during pregnancy, studies concurred that pregnancy itself is a life event which leads to a drastic decrease in exercise among many women (Brown & Trost, 2003; Godin et al., 1986; Mottola, 2002). For example, when Pereira et al. examined the longitudinal changes in PA from pre-pregnancy to the post-partum period, they reported 2.7 hours per week of decline in self-reported total PA from pre-pregnancy (9.6 hr/wk) to the 2nd trimester of pregnancy (6.9 hr/wk) (n = 1442) (Pereira et al., 2007). When Cramp and Bray examined the patterns of pre- and postnatal women’s leisure time PA (LTPA), using a multilevel longitudinal analysis (n = 309), the average growth curve showed a gradual decline in LTPA (MET-hr/month) during pregnancy compared to pre-pregnancy levels (A. Cramp & Bray, 2009). In this example, LTPA did not
include occupational, household, and caregiving activities. The prevalence of pregnant women who met PA guidelines was generally low.

Using the NHANES 1999 – 2006 self-reported cross-sectional PA data, Evenson and Wen noted that only 22.9% of pregnant women met the 2008 recommendations for physical activity when vigorous activities were included (Evenson & Wen, 2010). When PA was objectively measured using an ActiGraph accelerometer in the NHANES 2003 – 2006 cross-sectional data (n = 359) (Evenson & Wen, 2011), it showed that pregnant women only participated in an average of 12.0 ± 0.86 minutes/day of moderate activity and 0.3 ± 0.08 minutes/day of vigorous activity using the threshold cutpoints of Troiano et al (Troiano et al., 2008). When sedentary behavior was measured, the authors reported that pregnant women spent 57.1% of their monitored time in this category of activities.

There are also differences in prenatal PA behaviors across pregnancy. After evaluating 31 pregnancy and exercise studies, Poudevigne and O’Connor concluded that as pregnancy progresses, PA participation decreases especially in leisure and work-related PA categories (Poudevigne & Connor, 2006). In a cross-sectional survey (n = 467), Haakstad et al. demonstrated that 30% of the women were defined as non-exercisers in the first trimester, 36% in the second trimester and 53% in the third trimester. The definition of regular exercise used in this study was vigorous recreational PA at least 20 min once a week (Haakstad et al., 2007). As for epidemiological evidence, NHANES 1999 – 2006 self-reported PA data showed significantly lower moderate to vigorous LTPA among women in the third trimester compared to women in the first trimester (Evenson & Wen, 2010); whereas, according to the objectively measured PA, U.S. pregnant women spent 11.5
minutes/day at the first trimester, 14.3 minutes/day at the second trimester, and 7.6 minutes/day at the third trimester in moderate to vigorous PA (Evenson & Wen, 2011).

When examining the type of activities performed by pregnant women, Clissold et al. found that women who remained active during pregnancy changed their activity from sports, fitness classes and jogging to walking, swimming and gardening (Clissold, Hopkins, & Seddon, 1991). One study from Sweden demonstrated that a water aerobics program was more effective than a land-based PA program in decreasing pregnancy-related low back pain due to the weightlessness in water (Granath, Hellgren, & Gunnarsson, 2006). More recently, Field suggested that other low-intensity exercise, such as water aerobics, yoga and tai chi could be safer and more desirable for pregnant women (Field, 2012). Evenson and Wen reported the most common type of leisure activities among the 1280 pregnant women in the NHANES 1999 – 2006 data was walking (40%), followed by recreational activities (18.6%), and indoor aerobic conditioning activities (11.8%) (Evenson & Wen, 2010).

i) Walking during pregnancy

Walking is a common and popular choice of PA during pregnancy. It could be due to its lower intensity and higher accessibility compared with some other LTPA. When Mottola and Campbell evaluated activity patterns during pregnancy, they found that all categories of activity decreased except walking, which actually increased significantly by the 3rd trimester among the 529 women they surveyed (Mottola & Campbell, 2003). When the Project Viva team assessed change in LTPA from pre-pregnancy to mid-pregnancy (26 – 28 weeks of gestation) and six months postpartum, they found that total activity decreased significantly from pre-pregnancy to mid-pregnancy, and it remained low at six months postpartum. However, when the total amount of time spent walking was assessed, it only decreased
slightly from pre-pregnancy to mid-pregnancy, but it rebounded at six months postpartum, and exceeded the pre-pregnancy level (Pereira et al., 2007). In observational studies, walking at a brisk pace has been shown to reduce the risk of gestational diabetes (C. Zhang, Solomon, Manson, & Hu, 2006), pre-eclampsia (Saftlas, Logsdon-Sackett, Wang, Woolson, & Bracken, 2004), excessive GWG (Stuebe et al., 2009), and macrosomia (Owe, Nystad, & Bo, 2009).

Due to the growth of fetal tissue, the elevated basal metabolic rate and increased energy cost of moving a heavier body, overall energy requirements are higher during pregnancy (Prentice et al., 1996). In fact, according to Hytten’s estimate, in a well-nourished woman, the energy cost of pregnancy is approximately 335 MJ (80,000 kcal), but women may compensate this energy cost by selecting less demanding activities and reducing the pace of activities (Prentice et al., 1996). In terms of walking during pregnancy, thus far, three studies demonstrated that pregnant women walked at a slower pace as their pregnancy progressed or when walking pace among pregnant women was compared with a non-pregnant population (DiNallo, Le Masurier, Williams, & Downs, 2008; Löf, 2011; van Raaij, Schonk, Vermaat-Miedema, Peek, & Hutvast, 1990). Under the laboratory condition, DiNallo et al. noted that self-selected walking pace at 32 weeks (mean = 2.8 m/h; SD = 0.5) was significantly lower than the self-selected walking pace at 20 weeks (3.1 m/h, SD = 0.6) when women walked on a treadmill. The estimated mean activity counts from the ActiGraph accelerometer also showed significantly lower estimated mean activity counts at 32 weeks (mean = 1,662.6 counts, SD = 513.3) compared to 20 weeks (mean = 2,291.9 counts, SD = 659.9) (DiNallo et al., 2008). While, under free living conditions, Löf compared the activity energy expenditure between pregnant (n = 18) and non-pregnant (n = 21) populations using
the Intelligent Device for Energy Expenditure and Physical Activity (IDEEA) and doubly-labeled water (Löf, 2011). The study showed that, on average, pregnant women (1.1 ± 0.1 m/s) walked at a significantly slower pace than non-pregnant women (1.2 ± 0.1 m/s).

It is stated in the 2008 Physical Activity Guidelines for Americans that some activity is better than none (“Physical activity guidelines advisory committee report, 2008. To the Secretary of Health and Human Services. Part A: executive summary,” 2009). Even though pregnant women might not be as efficient as non-pregnant women when it comes to PA participation, it is still necessary to encourage pregnant women to engage in PA as it is safe for them and the health benefits appear to outweigh the risks.

b) Impact of PA on maternal and child health

As mentioned above, prenatal PA is generally safe for healthy pregnant women. Strong scientific evidence shows that the risks of moderate-intensity activity performed by healthy women during pregnancy are very low, and do not increase the risk of low birth weight, preterm delivery, or early miscarriage (Downs et al., 2012). In general, the fetus is not deprived of substrate (i.e.: glucose) during periods of maternal PA among well-nourished women and women who have an adequate ingestion of nutrients throughout the day. In fact, many human and animals studies have shown that glucose and oxygen delivery to the fetus is not compromised due to maternal exercise in uncomplicated singleton pregnancies (J F Clapp, Little, Appleby-Wineberg, & Widness, 1995; James F. Clapp, 2003; Lotgering, Gilbert, & Longo, 1983, 1985). An acute period of fetal hypoglycemia may occur at the onset of maternal PA; however, a greater placental surface area available for glucose uptake in active women might help compensate for this shortage (James F. Clapp, 2003). Even among pregnant women who did not exercise regularly, previous work showed that
maternal PA did not impact uteroplacental blood flow as measured by ultrasound scans immediately after a graded exercise test in a laboratory condition (Kennelly et al., 2002).

In terms of the fetal responses to maternal PA, ACOG 2002 guidelines stated that most of the potential fetal risks are hypothetical, and fetal injuries are highly unlikely (Artal & O’Toole, 2003). Instead of harming the fetus, regular aerobic exercise during pregnancy has shown to help with fetal cardiovascular development. Infants of pregnant women who performed routine workouts during gestation have improved heart rate and heart rate variability (May, Glaros, Yeh, Clapp, & Gustafson, 2010). In addition, maternal PA does not increase the risk of delivering SGA newborns (Hegaard, Pedersen, Nielsen, & Damm, 2007). Moderate PA during pregnancy seems to be protective against birth weight extremes with a high probability to deliver appropriate-for-gestational-age infants (AGA) (Z. Ferraro, Gaudet, & Adamo, 2012; Mudd et al., 2013). ACOG guidelines indicated that the risk of giving birth to an extremely low birth weight infant is rare in exercising pregnant women who consume an adequate energy intake throughout the day (Artal & O’Toole, 2003). As a result, in summary, research over the past 20 years in the field of maternal PA suggests that any effects of PA on maternal and child health are unlikely to be negative, and it actually brings benefits to both mothers and offspring when it is performed according to recommendations and consent is given from health care providers.

Some of the positive health outcomes of PA during pregnancy include, but are not limited to a reduced risk of excessive GWG (Stuebe et al., 2009), pre-eclampsia (Kasawara, Nascimento, Costa, Surita, & Silva, 2012), gestational diabetes (Dempsey et al., 2004), incidence of operative delivery (J F Clapp, 1990), and low back pain (Pivarnik et al., 2006).
The benefits of maternal PA on excessive GWG and offspring health and development are discussed further, below.

i) Maternal PA and excessive GWG

Thus far, many observational studies have supported the role of PA in helping pregnant women to minimize, if not prevent excessive GWG (J. Clapp & Little, 1995; Haakstad et al., 2007; Olson & Strawderman, 2003; Stuebe et al., 2009). For example, when Olson and Strawderman used a population-based study (healthy pregnant women from Upstate New York, n = 622) to examine some of the modifiable behavioral and psychosocial factors in relation to GWG, they found that women who decreased compared to those who maintained or increased their PA participation during pregnancy had a significantly greater GWG (2.74 lbs, p < 0.01) (Olson & Strawderman, 2003). Unfortunately, in this study the details of the frequency and duration of PA participation of the women prior to and during pregnancy were not discussed. However, when Clapp and Little evaluated the effects of recreational exercise on pregnancy weight gain among previously active women (routinely exercised three or more times a week for 30+ min a session), their results supported the findings of Olson and Strawderman (J. Clapp & Little, 1995). In this study, they found that women who continued their workout regimen throughout pregnancy compared to those who stopped their workout either before conception or in early pregnancy had a significantly (p < 0.05) lower rate of weight gain from week 15 to 30 (0.47 kg/wk vs. 0.57 kg/wk), and 30 to 37 (0.31 kg/wk vs. 0.47 kg/wk). Additionally, they also demonstrated that women who continued an active lifestyle during pregnancy had a lower subcutaneous fat deposit compared to those who were inactive during gestation by measuring the skinfold thickness at five different sites (11 ± 1 mm vs. 24 ± 2 mm; p < 0.001). When PA participation was
assessed among 1388 women from the Project Viva cohort study, Stuebe and colleagues reported an inverse relationship between excessive GWG with mid-pregnancy walking (OR 0.91; 95% CI: 0.82 – 1.00, per half-hour/day) and vigorous PA participation (OR 0.76; 95% CI: 0.60 – 0.97, per half-hour/day) (Stuebe et al., 2009). Moreover, this positive impact of maternal PA participation on excessive GWG has been observed in other countries, such as Canada (Cohen, Plourde, & Koski, 2010), Norway (Haakstad et al., 2007) and China (Jiang et al., 2012).

Aside from observational studies, many interventions have been conducted in the past decade to examine the effectiveness of healthy lifestyle with the incorporation of prenatal PA to limit GWG. The findings of these studies are generally inconsistent. Some interventions successfully (Claesson et al., 2008; Hui et al., 2012; Mottola et al., 2010; Shirazian, Monteith, Friedman, & Rebarber, 2010), partially successfully (Asbee et al., 2009; Barakat, Lucia, & Ruiz, 2009; Haakstad & Bø, 2011; Phelan et al., 2011; Polley, Wing, & Sims, 2002) or non-successfully (Guelinckx, Devlieger, Mullie, & Vansant, 2010; Kinnunen et al., 2007; Phelan et al., 2011; Polley et al., 2002) helped women to minimize GWG. The inconsistent results of these studies could be due to the differences in the type, intensity, duration and frequency of the activities included. Besides that, the various population and demographic characteristics of study participants could play a role in the varying outcomes.

Mottola et al. conducted a case-controlled trial to assess the impact of combined nutrition restriction and a walking program on prevention of excessive weight gain in overweight Canadian pregnant women (NELIP) (Mottola et al., 2010). Seventy-five overweight women (BMI 25.0 – 29.9) were recruited between 16 – 20 weeks gestation to
participate in the intervention until they delivered. The walking program was individualized to reach 30% peak HR reserve of the participant and it was performed three to four times a week (40 min per session) under supervision. The results of this intervention showed that 80% of the participants did not exceed IOM recommendations on NELIP and their average total weight gain on NELIP was only 6.8 ± 4.1 kg. Unfortunately, many women had gained excessive weight before they joined the program, which lead to an average of 12.0 ± 5.7 kg total weight gain by the end of the intervention. Mottola and colleagues also observed a significant increase in average daily step counts from the baseline value of 5677.6 ± 1738.0 steps to more than 10,000 steps per day.

On the other hand, when Phelan et al. conducted the Fit for Delivery Study, largest randomized controlled trial (n = 401) to date, to evaluate the effectiveness of behavioral lifestyle intervention on minimizing excessive weight gain they only found success in normal weight pregnant women (Phelan et al., 2011). This intervention is considered one of the most comprehensive programs, as education and advice on GWG, prenatal PA and healthy eating during pregnancy were included. This multi-component program included: i) one individual counseling with an interventionist at treatment onset to discuss appropriate GWG, PA (30 min of walking most days of the week), and calorie goals (20 kcal/kg) with the emphasis on fat intake reduction; ii) daily self-monitoring was encouraged by providing body-weight scales, food records, and pedometers for home-use; iii) automated postcards were mailed weekly to prompt healthy eating and exercise habits; iv) personalized graphs for weight gain were mailed after each prenatal visit to provide feedback; v) three brief (10 – 15 min) supportive phone calls were provided by dietitians during the intervention; vi) supplementary supportive phone calls (2 calls/month) were provided for women, who were
over or under, weight gain guidelines to help with meal planning and goal setting. Intent-to-treat analyses showed that normal-weight women in the intervention group were less likely than women in the usual care group to gain above the IOM recommendations (40.2% vs. 52.1%, $p = 0.003$), but there were no differences between the groups of overweight or obese women (66.7% vs. 61.1%, $p = 0.33$). However, both normal weight and overweight/obese women in the intervention were more likely to achieve their pre-conception weight or below at 6-months post-partum (OR: 2.1, 95% CI: 1.3 – 3.5, $p = 0.005$). As previously mentioned, this RCT was a multi-component intervention, in which prenatal PA was not the sole recommendation given to the pregnant women to limit excessive GWG.

In summary, maternal PA has the potential to prevent excessive GWG; therefore, the need to identify strategies to help pregnant women to increase their PA participation during pregnancy becomes critical in light of the increasing obesity prevalence.

ii) Maternal PA and offspring birth weight and body composition

Maternal PA has been associated with delivering SGA infants; however, the limitations of these studies include little or no information on nutritional status and caloric intake of women during pregnancy, and there is no control for other confounding factors that could affect birth weight, such as gestational age at birth, socioeconomic status or environmental factors. Besides that, many of these studies involved a small number of participants who were lean and physically active pregnant women (i.e.: athletes), which is likely not generalizable to other populations (Z. Ferraro et al., 2012; Hopkins & Cutfield, 2011). On the contrary, in some large population-based observational studies, data showed that maternal PA participation increased the likelihood of giving birth to AGA infant. Most importantly, maternal PA helped to reduce the risk of giving birth to a LGA infant by not
increasing the odds for a SGA infant (Juhl, Olsen, Andersen, Nøhr, & Andersen, 2010; Mudd et al., 2012; Owe et al., 2009). For example, data from the Norwegian Mother and Child Cohort Study (MoBa) of 16,064 nulliparous women with singleton pregnancies showed that there was a decreased risk of macrosomia in women who regularly exercised at least three times per week during week 17 (OR 0.72; 95% CI: 0.56 – 0.93) and week 30 (OR 0.77; 95% CI: 0.61 – 0.96) of gestation compared to those who did less than three times per week (Owe et al., 2009). However, in this study the duration and intensity of each bout of exercise was not characterized.

In another large cohort observational study (n = 79,692), Juhl et al. supported the findings of Owe by examining the dose-response of workout (duration) with risk of macrosomia (Juhl et al., 2010). They found that the higher the amounts of time (h/wk) the women spent in PA participation during pregnancy, the lower the risk of delivering LGA infants; however, again, the intensity of the workout regimen was not mentioned. In two smaller cohorts of observational studies, women who participated for at least 120 min/wk of at least moderate PA during pregnancy had a significantly lower risk of delivering a LGA infant without increasing the risk for a SGA infant (Alderman, Zhao, Holt, Watts, & Beresford, 1998; Mudd et al., 2012).

In terms of the association between maternal PA participation and body composition of the infant, there are only three studies, all from Clapp and colleagues. Two studies were observational studies where recruited women were recreational athletes (i.e.: runners, cross-country skiers) (J F Clapp, Simonian, Lopez, Appleby-Wineberg, & Harcar-Sevcik, 1998; J F Clapp, 1996) and one of the studies was a randomized controlled trial with no information about pre-pregnancy PA participation (J F Clapp, Kim, Burciu, & Lopez, 2000). In the first
observational study conducted in 1996, Clapp and colleagues compared women who continued their exercise regimens (aerobic activities three or more times per week, for more than 30 min a session with intensity greater than 55% of maximal capacity) during pregnancy with women who voluntarily stopped all sustained exercise besides walking (no information on intensity, duration and frequency were given by author) during pregnancy and found that the offspring of women who continued their exercise regimens during pregnancy were smaller (3.40 ± 0.80 vs. 3.64 ± 0.70 kg) and had less fat (10.5% ± 0.9% vs. 15.1% ± 0.6%) (J F Clapp, 1996). Two years later, Clapp conducted another study, which confirmed his previous findings (J F Clapp et al., 1998). However, in this study the women in the control group did not engage in anything more than occasional (less than once a month) recreational PA, and less than once a week, they would go on an after-dinner walk. Based on the findings of these two observational studies, Clapp and colleagues decided to conduct a randomized controlled trial (J F Clapp et al., 2000). They assigned groups of women at 8 weeks of gestation to either the control (no exercise, n = 24) or intervention (weight-bearing exercise for 3 to 5 times per week, n = 22) groups. Unlike what was found in the previous observational studies, the offspring of the exercising group were significantly heavier (3.75 ± 0.08 vs. 3.49 ± 0.07 kg) and longer (51.8 ± 0.3 vs. 50.3 ± 0.3 cm) and there was no significant difference in neonatal percent body fat. The heavier offspring of the exercising women was the result of an increase in both lean and fat body mass. Therefore, the authors concluded that beginning a moderate PA program in early pregnancy and continuing throughout pregnancy improved the fetoplacental growth.

Infants who were born LGA were more likely to be overweight or obese later in life; therefore, it is possible that offspring born AGA by women who participated in PA during
pregnancy could reverse this adverse long-term health outcome. Unfortunately, to date, there is limited research in examining the long-term longitudinal data on post-natal growth in the offspring of women who engaged in maternal PA during pregnancy. Again, there are currently three such studies in the literature, and two of them are the follow-up studies of Clapp and colleagues from the previously mentioned observational studies. Offspring of the exercising women continued to weigh less (18.0 ± 0.5 vs. 19.5 ± 0.6 kg) and were leaner (37 ± 1 vs. 44 ± 2 mm) at age 5 compared to the control group (J F Clapp, 1996). Surprisingly, the second observational study conducted did not have the same results, but the measurements in children were taken at age 1 instead of age 5 (J F Clapp et al., 1998). A more recent women/toddler pairs study (n = 23) conducted by Mattran et al. showed that recall of LTPA at 3rd trimester (MET-min/wk) was marginally associated with lower toddler weight ($r_s = -0.39$, $p = 0.06$) and weight-for-height $z$ score ($r_s = -0.40$, $p = 0.06$) between 18 to 24 months of age in the offspring (Mattran, Mudd, Rudey, & Kelly, 2011).

Overall, maternal PA is beneficial in reducing the odds of delivering a LGA infant. Strong scientific evidence shows that maternal obesity and excessive GWG are two of the major risk factors for delivering LGA infants. With the increasing prevalence of high birth weight (> 4.5 kg) and LGA babies (Ananth & Wen, 2002; Hadfield et al., 2009; Surkan, Hsieh, Johansson, Dickman, & Cnattingius, 2005), maternal PA may be advantageous for overweight or obese pregnant women. Moreover, the impact of maternal PA participation on postnatal growth in the offspring of overweight and obese pregnant women has not been studied. Therefore, with a robust positive relationship between birth weight and BMI in childhood and adulthood, reduction in birth weight of children of overweight and obese
women and prevention of excessive GWG through PA participation during pregnancy may bring valuable benefits to public health.

c) Barriers and predictors of PA participation during pregnancy

Despite the demonstrated benefits of engaging in regular PA, and the recommendations set forth by public health agencies, many pregnant women still do not meet the PA recommendations. As a result, there is a need to understand what barriers prevent women from engaging in prenatal PA and what factors predict women’s PA participation.

After reviewing approximately 300 studies on adult PA correlates, Sallis and colleagues concluded that perceived barriers are among the most cited psychosocial PA correlates (Sallis, Owen, & Fisher, 2008). When examining someone’s barriers to PA, a multilevel ecological approach seems to provide the best understanding of this very complex, interwoven relationship (Downs et al., 2012; Evenson, Moos, Carrier, & Siega-Riz, 2009). The components of socioecological framework include intrapersonal, interpersonal, environmental, and policy-related factors. Pregnancy is a period of complex social, psychological, behavioral and biological change in a woman’s life (Devine, Bove, & Olson, 2000). Consequently, there are many barriers that can prevent pregnant women from engaging in PA.

At the intrapersonal level, studies have reported that physical discomfort (i.e.: nausea, fatigue, back pain, swollen feet) (A. G. Cramp & Bray, 2009; Evenson et al., 2009; Leiferman, Swibas, Koiness, Marshall, & Dunn, 2011), embarrassment about appearance (Kieffer, Willis, Arellano, & Guzman, 2002), concern about safety and injury (Evenson et al., 2009; Leiferman et al., 2011), incorrect or lack of information from physicians
(Leiferman et al., 2011), lack of motivation (A. G. Cramp & Bray, 2009; Evenson et al.,
2009; Leiferman et al., 2011), and lack of time (A. G. Cramp & Bray, 2009; Evenson et al.,
2009; Leiferman et al., 2011) are some of the collective barriers described by pregnant
women pertaining to prenatal PA. Two common interpersonal barriers most mentioned by
women are the lack of social support (Evenson et al., 2009; Kieffer et al., 2002; Leiferman
et al., 2011), and social norms (Evenson et al., 2009; Kieffer et al., 2002; Leiferman et al.,
2011). Environmental barriers include lack of access to available resources (i.e.: safe parks,
trails, gyms) (Evenson et al., 2009; Kieffer et al., 2002; Leiferman et al., 2011), no childcare
support (A. G. Cramp & Bray, 2009; Evenson et al., 2009; Kieffer et al., 2002), and
weather-related concerns (A. G. Cramp & Bray, 2009; Evenson et al., 2009; Leiferman et
al., 2011). Lastly, some pregnant women faced policy-related barriers. There were 5% of
women in the Pregnancy, Infection, and Nutrition (PIN) Study that reported barriers in this
category, which were mainly conflicts with work or school, and the cost of workout
facilities (Evenson et al., 2009).

Numerous studies have examined the association of theory-based psychosocial
factors in predicting PA participation during pregnancy (Gaston & Cramp, 2011). These
factors have been mainly investigated from the perspectives of the Theory of Planned
Behavior (Downs & Hausenblas, 2007; H. Hausenblas & Symons Downs, 2004; H.
Hausenblas, Downs, Giacobbi, Tuccitto, & Cook, 2008; Symons Downs & Hausenblas,
2003; Weir et al., 2010), the socioecologic framework (Evenson et al., 2009; Leiferman et
al., 2011), and the social cognitive theory (A. G. Cramp & Bray, 2009). Among these
psychosocial factors, self-efficacy (a component the social cognitive theory) has yielded the
most consistent positive relationship with PA participation during pregnancy. Self-efficacy
is the belief in one’s capabilities to put forth the necessary effort to overcome various challenges (Bandura, 1997). It influences the adoption, initiation, and maintenance of health behaviors such as leisure time PA participation (Sallis et al., 1986; Sallis, Hovell, & Hofstetter, 1992). Studies have shown that self-efficacy strongly correlates to PA participation among diverse populations including children, men, and non-pregnant women (McAuley & Blissmer, 2000; Motl, Snook, McAuley, Scott, & Douglass, 2006; Sharpe et al., 2008; Strauss, Rodzilsky, Burack, & Colin, 2001; T.-Y. Wu, Pender, & Noureddine, 2003).

Self-efficacy is likely an important factor that needs to be targeted in behavioral interventions among the pregnant population (Oken & Gillman, 2012). Hinton and Olson (Hinton & Olson, 2001) examined the psychosocial predictors of pregnancy-related changes in PA participation, and they concluded that exercise self-efficacy was a key predictor of PA participation during the perinatal period after controlling for age, prepregnancy BMI, and frequency of prepregnancy exercise. Further, Cramp and Bray (A. G. Cramp & Bray, 2009) completed an observational study that supported the findings of Hinton and Olson. In this cross-sectional study, they demonstrated that exercise self-efficacy (barrier and task self-efficacy) independently predicted LTPA across pregnancy (at week 18, 24, 30 and 35 of gestation). In this study, barrier self-efficacy was defined as “anything that may stop you from doing physical activity”; while task self-efficacy was defined as confidence in their ability to participate in LTPA during pregnancy.

In summary, identifying barriers to PA during pregnancy and predictors that motivate women from engaging in prenatal PA are crucial. Unlike the sociodemographic
correlates, psychosocial correlates like barriers and self-efficacy are modifiable characteristics, which could be targets for interventions.

**B) Maternal diet**

There is an increased maternal nutritional requirement during pregnancy. The energy need during the first trimester of pregnancy is no different from that of non-pregnant women, but it increases an additional 340 kcal per day in the second trimester, and 452 kcal per day in the third trimester (Kaiser & Allen, 2008). Total daily calorie intake for most pregnant women is between 2,200 to 2,900 kcal per day, but this recommendation should be individualized based on prepregnancy BMI, rate of weight gain, maternal age and appetite according to the American Dietetic Association positioning report (Kaiser & Allen, 2008). Pregnant women are also advised to consume a variety of foods to meet the higher need for specific vitamins and minerals. Currently, most health care providers would recommend pregnant women take a daily prenatal vitamin and mineral supplement; however, these supplements should not replace a healthy diet. In order to better facilitate the special needs of the pregnant population in the United States, ChooseMyPlate.gov has a special section of the website for pregnant women called “Daily Food Plan for Moms”, where pregnant women can make a food plan that covers individual energy needs and it also guides women to make good food choices during pregnancy (ChooseMyPlate.gov, 2013).

Unfortunately, many women of childbearing age in the U.S. do not maintain good nutritional status before, during and after pregnancy (Kaiser & Allen, 2008). Studies have shown that maternal dietary factors can significantly influence the health outcomes of the mother and baby (Camargo et al., 2007; Hibbeln et al., 2007; King, 2000; Moon et al., 2013; Rifas-Shiman, Rich-Edwards, Kleinman, Oken, & Gillman, 2009; Scholl, Hediger, Schall,
Khoo, & Fischer, 1996). In more recent years, researchers also demonstrated that maternal high fat diets or “junk food” diets, which consisted of high-fat, sugar and salt, during pregnancy and lactation contributed to the development of offspring obesity (S. A. Bayol, Simbi, Bertrand, & Stickland, 2008; Stéphanie A. Bayol, Farrington, & Stickland, 2007; Franco et al., 2012). Project Viva examined the dietary quality of pregnant women (n = 1,777) using the Alternate Healthy Eating Index- Pregnancy (AHEI-P) on a 90-point scale (10 points for each component), and the average score of the women was 61 ± 10 (minimum 33, maximum 89) (Rifas-Shiman et al., 2009). The nine dietary components of AHEI-P include vegetables, fruit, ratio of white to red meat, fiber, trans-fat, ratio of polyunsaturated to saturated fatty acids, folate, calcium and iron. Food-frequency questionnaires were used to collect the dietary intake of the participants; however, in order to have a meaningful interpretation of the diet quality, results were simplified into this composite score. Participants in the study, who were younger (-1.3 points per 5 years, 95% CI: -1.8 – -0.7), less educated (-5.2 points for high school or less vs. college graduate, 95% CI: -7.0 – -3.5), had more children (-1.5 points per child, 95% CI: -2.2 – -0.8), and who had higher pre-pregnancy BMI (-0.9 points per 5 k/m², 95% CI: -1.3 – -0.4), had poorer-quality diets. They also observed that the lower the AHEI-P score, the higher the blood glucose levels of the women at the first trimester, and the higher the risk of developing pre-eclampsia at the second trimester.

Good maternal nutrition does not only benefit the mother, but it is also a key factor for the health of our next generation. Health-promoting strategies which support a healthful-balanced diet and active lifestyle cannot be taken lightly during pregnancy. A substantial
body of evidence supports the notion that pregnancy could be an ideal time to make healthy lifestyle choices.

C) Pregnancy-specific lifestyle interventions

a) Overview of the effectiveness of current lifestyle interventions on GWG

Eleven systematic or meta-analysis reviews published in English between 2010-2012 addressed the effect of lifestyle interventions, either by modifying PA, and/or diet, on GWG and/or proportion of women exceeding the IOM guidelines were identified. Some of these reviews only included randomized-controlled trials (RCTs), but some included both RCTs and non-randomized interventions. Many of the earliest and highly cited interventions on reducing excessive GWG were non-randomized interventions (Oken & Gillman, 2012).

i) Physical activity and/or dietary lifestyle interventions

Among the 11 reviews, 7 included PA and/or dietary lifestyle interventions: four of these reviews concluded that PA and/or dietary lifestyle interventions successfully minimized GWG (Gardner, Wardle, Poston, & Croker, 2011; Oteng-Ntim, Varma, Croker, Poston, & Doyle, 2012; Ina Streuling, Beyerlein, & Kries, 2010; Thangaratinam et al., 2012); two reviews did not provide conclusive results (Mudd et al., 2013; Ronnberg & Nilsson, 2010; Skouteris et al., 2010) and one review found no significant difference in GWG among participants in the intervention group compared to the control group (Campbell, Johnson, Messina, Guillaume, & Goyder, 2011).

In the Streuling et al. meta-analysis, only articles in English and German were included. The review was comprised of four RCTs and five non-randomized trials with a total of 1549 women. When random-effects model analysis was performed to quantify the effect estimates, a significant (p = 0.01) reduction of the standardized mean difference
(SMD) of -0.22 units (95% CI: -0.33 – -0.03) in the intervention groups was observed. This corresponded to an average of 1.2 kg GWG reduction, indicating a clinically relevant result (Ina Streuling et al., 2010). The authors also observed that interventions supplemented with weight monitoring had an additional beneficial effect on weight reduction.

The results of Streuling et al. were supported by another more comprehensive meta-analysis performed by Thangaratinam et al. (Thangaratinam et al., 2012). This meta-analysis included all published randomized controlled trials (44 RCTs, n = 7278) with no language restrictions. The results showed that there was a 1.42 kg reduction (95% CI: 0.95 – 1.89) in GWG with any intervention (diet, PA, and a mixed approach) compared with control; however, the largest reduction was found in dietary interventions (3.84 kg; 95% CI: 2.45 – 5.22, p < 0.001). Unfortunately, this meta-analysis showed that there was no significant difference between the groups in meeting the IOM weight gain recommendations (relative risk 0.85; 95% CI: 0.66 – 1.1).

When evaluating lifestyle interventions aimed at overweight and obese pregnant women, Oteng-Ntime and colleagues included thirteen RCT and six non-RCTs in their meta-analysis and systematic review (Oteng-Ntim et al., 2012). All of these trials were performed in developed countries and 16 out of the 19 trials measured GWG. The findings of this study showed that weight reduction was only significant in RCTs (10 studies, n = 1,228, -2.21 kg; 95% CI: -2.86 – -1.57), but not in non-RCTs (6 studies, n = 1,534; -0.42 kg; 95% CI: -1.03 – 0.19) among the overweight and obese pregnant women.

The last meta-analysis, which showed positive results in changing diet and PA to reduce GWG, is from Gardner et al. (Gardner et al., 2011). This is a novel meta-analysis, in that the authors deconstructed the different aspects of the intervention content by identifying
the use of theoretical basis, and behavioral change techniques in the studies. Among the

twelve RCTs included in the analysis, Gardner et al. only identified two interventions
reporting the use of behavioral theories to inform intervention design: one mentioned the use
of social learning theory (Gray-donald et al., 2000), and the other used precede-proceed and
transtheoretical model (Kinnunen et al., 2007). However, neither of the study authors
included detail regarding how the theoretical constructs were used to develop the
interventions. Gardner et al. also identified 16 of the 40 behavioral techniques described by
Michie et al. (Michie et al., 2011) in 10 of the RCTs. The three most commonly used
techniques were self-monitoring (8 trials), provision of feedback on performance (6 trials),
and goal-setting (5 trials); however, none of these techniques were particularly effective.
The overall findings of the paper showed that the 12 RCTs were effective in minimizing
weight gain among the pregnant women in the intervention group compared to the control
group with a weighted mean difference (WMD) of -1.19 kg (95% CI: -1.74 – -0.65, \( p <
0.0001 \)); however, two of the theoretical based interventions had no effect on weight gain
(WMD = -0.41, 95% CI: -1.76 – 0.95, \( p < 0.56 \)). The authors concluded that it could be that
inappropriate theories were used in these studies that lead to the ineffectiveness, especially
when no detail in regard to the theories was given.

Two review articles showed that PA and/or diet interventions provided inconclusive
and inconsistent results in minimizing excessive GWG. Skouteris et al. demonstrated that
even though six out of the total ten studies (RCTs and non-RCTs) reported significantly
lower weight gain among women in the intervention compared to control, the intervention
program only affected one group of participants (e.g. normal-weight women, low-income
women, obese women), but not uniformly across all participants in the same intervention.
Three out of these six studies showed that women in the intervention group were more likely to meet the IOM guidelines. Interventions that significantly improved diet or PA were not successful in reducing GWG. Therefore, the authors concluded that the most appropriate factors to be targeted in interventions to reduce GWG remain unknown. The findings of Skouteris were further supported by Ronnberg and Nilsson, who assessed all available RCTs and non-RCTs with total or rate of GWG as the primary outcomes using the Grading of Recommendations, Assessment, Development and Evaluation (GRADE) system, which is a system for rating quality of evidence in systematic reviews and guidelines using a structured process (Ronnberg & Nilsson, 2010). Among all eight studies included in the review, a majority of them showed no significant difference in rate of weight gain or proportion exceeding IOM weight gain guidelines. In summary, the assessment found that there were important limitations in study design, inconsistency, and lack of directness; therefore, the overall quality of published interventions was judged to be very poor.

The objective of the systematic review performed by Campbell et al. in 2011 was to assess the effectiveness of behavioral interventions to prevent excessive GWG (using quantitative analysis) and to investigate the views of women on weight management during pregnancy (using qualitative analysis) (Campbell et al., 2011). The quantitative analysis showed that despite intense and often tailored intervention, there was no significant difference in GWG among participants in the intervention group compared to the control group (mean difference -0.28; 95% CI: -0.64 – 0.09). While the qualitative analysis showed that most women viewed pregnancy as a time of transition and change, the messages with regard to weight management in pregnancy were conflicting and contradictory and they perceived lack of control to maintain healthy weight gain during pregnancy. As a result,
when the authors aligned the quantitative and qualitative analyses, they concluded that some common barriers (i.e.: lack of information, contradictory information received and social support) pregnant women faced in gaining appropriate weight during pregnancy were not addressed by the interventions.

ii) Physical activity interventions

Thus far, only one meta-analysis has been performed to evaluate the impact of lifestyle intervention, with increasing PA as the only modification during pregnancy, on GWG (Streuling et al., 2011). Twelve RCTs were included in this analysis with trials varying by intensity, duration and mode of activity. Seven of the trials reported a trend for lowering GWG in the intervention group, one showed significant reduction in GWG, and five showed no significant effect. The overall meta-analysis finding demonstrated that PA modification indeed resulted in significant GWG reduction (mean difference of -0.61; 95% CI: -1.17 – -0.06, \( p = 0.03 \)). When the mean difference was plotted against METs per intervention, the graph showed no dose-dependent effect of exercise on GWG. The author of this study concluded that prenatal PA might be an ideal strategy to minimize excessive GWG.

iii) Dietary interventions

Two systematic reviews (Dodd, Grivell, Crowther, & Robinson, 2010; Tanentsapf, Heitmann, & Adegboye, 2011) and one meta-analysis (Quinlivan, Julania, & Lam, 2011) were conducted to evaluate the effectiveness of dietary interventions to prevent excessive GWG. In the Tanentsapf et al review, ten out of thirteen included trials reported total GWG; two reported weekly GWG and four reported percentage weight gain exceeding IOM weight recommendations. The results showed that dietary modification significantly reduced total
GWG in the intervention group (WMD = -1.92; 95% CI: -3.65 – -0.19, \( p = 0.03 \)), and significantly reduced weekly GWG (WMD = -0.26 kg/wk, 95% CI: -0.42 – -0.09, \( p = 0.003 \)), but did not lower the risk of women who gained more than IOM recommended weight (reduction in risk (RR) 0.90; 95% CI: 0.77 – 1.05, \( p = 0.18 \)). When Quinlivan and colleagues conducted a meta-analysis which focused on the overweight and obese population, they found that dietary interventions significantly restricted maternal weight gain during pregnancy, with a pooled mean difference of -6.5 kg (95% CI: -7.6 – -5.4) (Quinlivan et al., 2011). On the contrary, when Dodd and colleagues examined antenatal dietary interventions for overweight and obese women, they did not find a significant reduction in weight gain among the women who were in the intervention group (WMD = -3.10 kg; 95% CI: -8.32 – 2.13) when a random-effects model was used (Dodd et al., 2010).

To conclude, in the words of Ronnberg and Nisson “interventions designed to reduce excessive GWG still appear to be in their infancy” (Ronnberg & Nilsson, 2010). Many, if not all, of these systematic and meta-analysis reviews observed a trend of poor to low quality of the published interventions, heterogeneity of trials, and inconsistent results, especially across subgroups (e.g., income, weight category) (Oken & Gillman, 2012). It is seconded by a Cochrane Review that no one intervention thus far appears to be appropriate for preventing excessive GWG, which is due to the poor quality and small effect size of current published interventions (Muktabhant, Lumbiganon, Ngamjarus, & Dowswell, 2012). Fortunately, in recent years, numerous efforts have been invested to support research programs focused on this area. For example, in 2011, the US National Institutes of Health invited grant application proposals ‘to conduct studies testing behavioral/lifestyle interventions in overweight and obese pregnant women designed to improve weight and
metabolic outcomes in both the pregnant women and their offspring. Studies are expected to continue follow-up of mothers and their offspring for a minimum of 12 months post-partum. Weight and/or metabolic outcomes must be assessed in both mothers and offspring’ (Department of Health and Human Services, 2011). Optimistically, strategies to help women prevent excessive GWG that could lead to a better health for the mothers and children are within the reach in the next few years.

Overall, randomized controlled trials with adequate power are needed to provide evidence-based recommendations for health care providers to combat the issue of maternal obesity and/or excessive GWG. Additionally, there is also a lack of well-conducted trials demonstrating the benefits of antenatal lifestyle interventions on down-stream child growth and development outcomes, especially considering the issue of childhood obesity. Lastly, despite the consensus that intervention studies should be theoretically driven (Dishman, 2001), most prenatal PA intervention studies are not based on theoretical frameworks specifically targeting promotion of PA behavior. This has limited the mechanistic insight to intervention effectiveness. As a result, there is a need for theoretically driven randomized controlled trials to better understand the complex interactions among the psychological, behavioral, and biological determinants of prenatal PA (Downs et al., 2012). These trials would then serve as a foundation to develop strategies or recommendations for the obstetric providers to help women achieve optimal weight gain during pregnancy.

References:


CHAPTER 3: A RANDOMIZED-CONTROLLED WALKING INTERVENTION TO IMPROVE PREGNANCY AND BIRTH OUTCOMES BY PROMOTING MODERATE PHYSICAL ACTIVITY AMONG OVERWEIGHT AND OBESE PREGNANT WOMEN: MOMS TO MOVE (M2M) STUDY

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

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Abstract

Few studies have investigated the use of walking among overweight and obese pregnant women as a strategy for meeting the physical activity (PA) recommendation during pregnancy in order to limit excessive gestational weight gain (GWG). **Purpose:** To promote moderate PA participation among previously non-exercising, overweight and obese pregnant women, via walking, and to evaluate the impact of increased moderate PA on GWG and birth outcomes. **Methods:** Thirty seven overweight or obese (BMI ≥ 25.0 kg/m²) pregnant women were randomly assigned to a walking intervention versus no-intervention control group. Anthropometric, objective physical activity (StepWatch™ Activity Monitor), and self-reported diet data were collected for one-week at a time at each of the following gestational time point: weeks 10-14 (V1), 17-19 (V2), 27-29 (V3) and 34-36 (V4) of gestation. Participants provided information of the infant’s delivery and birth outcomes. Cadence of ≥80 steps/min was defined as moderately intense PA and “meaningful walking” was defined as moderately intense cadence in bouts of at least 8 minutes of walk. ANOVA was used to determine the differences in walking amount and meaningful walks; Kolmogorov-Smirnov test was used for walking intensity analysis; Fisher’s exact test was used for total GWG and
Results: There were significantly more moderately intense cadence (cadence $\geq 80$ steps/min) among the women in the intervention group compared to control group at V2 (overweight $p < 0.0001$; obese $p < 0.025$), V3 (overweight $p < 0.0001$; obese $p = 0.0722$), and V4 (overweight $p < 0.0001$; obese $p < 0.025$). Women in the intervention group also significantly increased their meaningful walks at V2 (diff = 32.6 min, $p = 0.054$), V3 (diff = 37.1 min, $p = 0.01$) and V4 (diff = 35.4 min, $p = 0.014$). Even though it was not statistically significant, there was a trend for women in the intervention group to have overall more favorable pregnancy and birth outcomes compared to the control group. Conclusion: The walking intervention increased the walking intensity and time spent in meaningful walking of all women enrolled in the intervention group during pregnancy. Key words: walking intensity, moderately intense cadence, pregnancy, gestational weight gain

Introduction

In the United States, approximately two-thirds of childbearing age women are either overweight or obese (46). There is increased risk of adverse maternal and fetal health outcomes, such as gestational diabetes (9), gestational hypertension or pre-eclampsia (6), and labor/delivery complications (58, 63) among overweight and obese pregnant women. Excessive gestational weight gain (GWG) is another concern in the field of maternal and child health. In 2009, the Institute of Medicine released updated GWG recommendations based on a woman’s pre-pregnancy BMI (46). The latest data showed that in the U.S., 63% of overweight and 65% of obese women exceeded the 2009 IOM GWG recommendations (59). Excessive GWG can be particularly concerning for overweight and obese women due to their already increased risk for adverse pregnancy outcomes. In addition, maternal obesity
and GWG are two of the main causes of giving birth to large-for-gestational-age (LGA) (birth weight ≥ 90th percentile) infants in most Western countries (2, 14, 34, 36). The influence of maternal obesity on offspring obesity may be sustained from childhood through adulthood (27, 28, 49, 60).

Healthy eating habits and regular physical activity (PA) are two modifiable targets in managing and preventing weight gain. These behaviors should be encouraged among pregnant women, too. In recent years, PA during pregnancy has been viewed as an important part of reproductive health. Pregnant women are encouraged to have an active lifestyle, which has replaced the traditional view that pregnant women should engage in limited exercise. The risks of moderate-intensity PA performed by healthy women during pregnancy are very low and do not increase the risk of low birth weight, preterm delivery, or early miscarriage (18). However, when examining the prevalence of PA participation for pregnant women, pregnancy appears to be a life event which leads to a drastic decrease in PA participation among many women (7, 22, 32).

Studies have suggested positive benefits of PA during pregnancy to both the mother and fetus including decreased risk of developing pre-eclampsia (26) and gestational diabetes (16), fewer incidences of operative deliveries (12), and decreased low back pain (41). Additionally, some observational studies have supported the role of PA in helping pregnant women to minimize, if not prevent, excessive GWG (11, 23, 37, 52). According to the American College of Obstetrics and Gynecology (ACOG) 2002 guidelines, in the absence of either medical or obstetric complications, pregnant women are encouraged to accumulate 30 minutes or more of moderate-intensity PA (MPA) on most, if not all days of the week (1). Later, when the U.S. Department of Health and Human Services issued the first-ever PA
guidelines for Americans (PAG) in 2008, they included recommendations for pregnant populations who are healthy and without medical complications (64). Different from the ACOG guidelines, the 2008 PA guidelines prescribe a total of 150 minutes of MPA per week (spread throughout the week) for pregnant women. Despite these recommendations, the evidence of US pregnant women meeting PA guidelines is low (20, 21). According to the NHANES 2003 – 2006 data, pregnant women only participated in an average of 12.0 ± 0.86 minutes/day of moderate activity and 0.3 ± 0.08 minutes/day of vigorous activity when their PA participation was objectively measured by ActiGraph accelerometer (21). With the higher risk of adverse maternal and fetal health outcomes along with an increased possibility of gaining excessive weight during gestation, it is imperative that strategies to promote MPA in this population be identified.

Interventions have been conducted to examine the effectiveness of healthy lifestyle with the incorporation of prenatal PA to limit GWG and/or proportion of women exceeding the 2009 IOM guidelines (5, 10, 24, 31, 40, 50). The findings of these intervention studies are generally inconsistent, possibly due to the differences in the type, intensity, duration and frequency of the activities included. Walking is a common and popular choice of PA during pregnancy because of its lower intensity and higher accessibility compared with some other leisure-time PA (LTPA) (30, 39). During pregnancy, all categories of activity decrease except walking (30). Few studies, if any, have investigated the use of walking among overweight and obese pregnant women as a strategy for meeting the recommendation of 150 minutes per week of moderate intensity PA during pregnancy in order to limit excessive GWG. Therefore, we conducted a pilot randomized controlled trial (RCT) to evaluate the feasibility of increasing PA participation of previously non-exercising, overweight and
obese pregnant women by walking. The objectives of this study were 1) to promote moderate PA participation among previously non-exercising, overweight and obese pregnant women, via walking; 2) and to evaluate the impact of increased moderate PA on pregnancy and birth outcomes. The hypotheses of the current study were that previously non-exercising, overweight and obese women could increase moderate PA participation during pregnancy via a walking intervention, and those who increased their moderate PA participation would have more favorable pregnancy and birth outcomes.

**Methods**

**Participants**

Recruitment for participants occurred from January 2011 to March 2012 through emails, online advertisements, and fliers posted throughout the community and at local obstetric clinics. Potential participants who expressed interest were screened for qualification criteria. Each participant was provided with an informed consent document for review. The study was approved by the Institutional Review Board of Iowa State University.

All pregnant women were recruited before they began their fifteenth week of gestation. Gestational age was calculated based on the self-reported date of the patients’ last normal menstrual cycle or the due date determined by their medical providers using ultrasound. Forty-six pregnant women enrolled in the study, and the final number of women who completed the study was 37 (n = 18 in intervention group; n = 19 in control group). Five women withdrew from the study (Figure 1). Participants who were enrolled met the following inclusion criteria: maternal age between 18-45 years old, singleton pregnancy, non-smoker, self-reported overweight (BMI ≥ 25.0 kg/m²) or obese (BMI ≥ 30.0 kg/m²)
prior to pregnancy, no prior history of chronic diseases (including type 1 diabetes, cardiovascular disease, thyroid disorder or lung disorder), and no prior history of gestational diabetes. In addition, only women who engaged in less than three times per week of LTPA for 30 minutes or more per session, 6-months preceding their enrollment into the study were recruited. Pre-pregnancy PA participation was self-reported (questions in the screening process) and LTPA was defined as activities performed each week beyond normal daily routines.

Study design

Procedure

Participants who met inclusion criteria were invited for an enrollment appointment prior to week 15 of gestation. During the enrollment, participants signed the consent form, filled out a medical history questionnaire, and provided their medical providers’ contact information. Height and weight of the women were measured by a trained staff member after the consent form was signed. All participants were approved by their medical providers to join the study. After the initial enrollment, participants were randomly assigned to the intervention or control group. Randomization was conducted using a computer-based random number generator (Microsoft Excel 2010, WA). All participants reported to the clinical research center at each of the following time points: weeks 10 – 14 (V1), 17 – 19 (V2), 27 – 29 (V3) and 34 – 36 (V4) of gestation. At each gestational data collection time point, anthropometric, objective PA, and self-reported diet data were collected for one-week at a time. Weeks 10 – 14 of gestation (V1) served as the baseline data collection period. Participants randomized to the intervention group had an additional intervention training
session after the baseline visit. Participants filled out a post-partum questionnaire that provided information regarding the infant’s delivery and birth outcomes.

**Intervention: walking program**

The intervention in this study was an unsupervised walking program. Immediately after the baseline data collection (V1), women in the intervention group attended a training session. At this session, the women were verbally given the 2008 U.S. Physical Activity Guidelines, which is to accumulate a minimum of 150 minutes per week of moderate PA during pregnancy. The women were advised to spread their walking throughout the week, such as 30 minutes of walking five days per week (1). The women were also given permission to walk in shorter bouts; however, they were advised to keep the bouts to at least 10 minutes (61). Walking could occur indoors, such as walking at the mall, or outdoors, such as walking at the park. To help participants in the intervention group achieve their walking goal, treadmills were provided to use in their homes for the duration of the study and were returned following the completion of the walking program. A treadmill was provided to eliminate some of the common prenatal PA barriers pregnant women face (13, 19). These barriers include, but are not limited to, lack of access to available resources (i.e.: gyms, trails), lack of childcare support, and weather-related concerns. The instructions and safety of using a treadmill was discussed with individual participants. A treadmill was delivered to the participant’s home and assembled by study staff. All treadmills were functioning when placed in the participant’s home and all treadmills were verified to be functioning when removed. A study staff member picked up the treadmill from the participant’s home at the end of the walking intervention period.
The walking program began no earlier than week 12 and no later than week 15 of gestation and lasted until at least week 35. Depending on the length of each participant’s pregnancy, all the intervention participants were able to complete at least 20 weeks of the walking program. The first three weeks of the intervention program served as an acclimation period. At week one, participants were asked to walk for at least 10 minutes per day and at least 5 days per week, followed by 20 minutes per day at week 2 and 30 minutes per day at week three. By week 18, all participants were encouraged to be at their walking goal of 30 minutes most days of the week for an overall total of at least 150 minutes of weekly moderate PA. During the acclimation period, participants received weekly contacts from the study coordinator to report their progression. Participants were also given a PA log to record the duration, method and location of their walks throughout the intervention period. They returned the PA logs to the study coordinator at each gestational data collection time point.

Women in the control group were not provided recommendations with respect to PA participation, but they were not restricted from any form of PA participation during pregnancy. They were also given a PA log to record any leisure activities (including walking) that they participated in throughout the study period. The control group was not given treadmills for home use.

**Data Collection**

**Anthropometric and demographic data**

Height and weight were measured at each gestational time point visit. Height was measured to the nearest 0.1 cm (Ayrton 226 Hite-Rite Precision Mechanical Stadiometer, Quick Medical GS, Snoqualmie, WA) and weight was measured to the nearest 0.1 kg (Detecto Model 6855 Cardinal Scale, Manufacturing Co., Webb City, MO). Pre-pregnancy
BMI was determined by using height measured at enrollment and women’s self-reported weight prior to conception. Total GWG was calculated by subtracting weight measured at V4 from self-reported pre-pregnancy weight. This value was used to determine if participants met the 2009 IOM recommendation after adjusting for their weeks of gestation at V4. Total GWG during M2M was calculated by subtracting weight measured at V4 from V1. Rate of GWG during M2M was then calculated by dividing total GWG during M2M from gestational weeks between V1 and V4. During enrollment, participants reported their age, education level, employment, race, marital status, income level, and parity. Infant birth weights and sex were obtained from the post-partum questionnaire. To maintain consistency, account for sex differences, and enable comparison of effect sizes, birth weights were converted to z-scores. Birth weights were adjusted to gestational age and sex-specific z-score (birth weight z-score) using US reference data (35).

**Objective physical activity data: StepWatch™ Activity Monitor**

Physical activity was monitored using the StepWatch™ Activity Monitor (SAM), an objective accelerometer-based measurement tool worn on the outer side of the right ankle 24 hours per day for one week. The SAM contains a microprocessor that uses a combination of acceleration, position, and timing to detect steps; therefore, the outputs of the SAM are based on the amount, rate, and pattern of walking. It is calibrated to the individual’s height. PA participation was determined using step data (counts) from the SAM. Instructions in regards to proper use (especially orientation) of the monitor were given to participants. For example, if the monitor was worn upside down, no step data was recorded, despite being worn on the ankle.

**Data processing**
SAM measured step data in one-minute epochs. In other words, SAM was used to detect the number of steps taken by the participants for each minute. The sample rate of the SAM is pre-set and there are no options to change the sampling settings. Individual primary SAM files were examined visually by graphing the data in order to detect non-wear time. Step count data was collected during 24-hour periods for 7 consecutive days. Data were excluded for a day if the participant did not wear the monitor (non-wear time or improper placement) for ≥ 300 consecutive minutes during typical waking hours (i.e. 7AM-10PM for most participants). In adults, it has been reported that at least 3 days of monitoring using accelerometry is required to provide reliable estimation of habitual PA (53); therefore, at each gestational time point data collection women who provided at least 3 valid days of step counts were included. The raw step data was smoothed using an exponential smoother (R: Moving averages, R Foundation for Statistical Computing, Vienna, Austria) to determine cadence (steps/minute) and bouts of walking among the participants. The weight used in the smoother formula was 1/10. Overall, the goal of this process was to help account for random stops (i.e.: waiting at a stop light) during any episode or bout of walking.

**Meaningful walk determination**

In order to determine the intensity of the walks, the number of steps taken per minute (cadence) was used. For a non-pregnant population, approximately 100 steps/minute equals a cadence of 3 metabolic equivalents of task (METs) with a walking range between 2.4 to 3 mph (56); however, this value was reported in laboratory conditions and was commonly measured using treadmills. It has been reported that the MET value of pregnant women (10 – 14 weeks gestation) who walked at 2 mph at 0% incline was 3.12 ± 0.32 (8). Therefore, in this study, a cadence ≥80 steps/min was defined as moderate intensity walking for pregnant
women under free-living conditions with the assumption that some of the women might walk outdoors (i.e.: parks, walking trails). Additionally, evidence shows that accumulated short bouts of brisk walking can improve aerobic fitness and physiological outcomes and that these bouts should be continuous activities for $\geq 10$ minutes in duration in the non-pregnant population (61). In addition to the use of cadence $\geq 80$ steps/min as the moderate activity cut point, slowing down from a walk and/or brief rest during a walk needed to be accounted for; therefore, the definition of meaningful walk in this study would be any steps taken at moderately intense cadence ($\geq 80$ steps/min), and must also be in bouts of at least 8 minutes of walk. In other words, meaningful walks are those walks that should be counted towards meeting the PA guidelines, which not only stress total time and bouts, but intensity.

**Dietary intake**

Three-day weighed diet records were collected at each data collection time point. All participants in the intervention and control groups were provided with a food log and a Precision Electronic Cuisinart scale (model SA-110A; Cuisinart, Newark, NJ) for one week at a time. Participants were asked to weigh (in grams) and document all food and beverages consumed for three days throughout a one-week period. The recording days consisted of two weekdays and one weekend day. A trained staff member provided each participant with explicit verbal and written instructions on how to weigh and document all foods and beverages using food models, scale, and food log.

**Post-partum questionnaire**

All participants completed a post-partum questionnaire. The questionnaire included pregnancy risks and labor procedures (i.e.: used of epidural, C-section delivery) as well as
infant’s birth outcomes (sex, anthropometric data and APGAR (appearance, pulse, grimace, activity, respiration) scores).

**Process Measures/Fidelity**

Physical activity logs provided for the participants were used to measure the compliance of the women who were in the walking intervention. They were asked to return the logs at each gestational time point data collection. The logs were visually examined and a trained staff member would discuss any issues or concerns arisen during the intervention period with the participants at those visits. Additionally, the PA level of the participants were measured for 1 week at a time during the gestational data collection periods. This PA measurement would allow the investigators to discern if the participants in the intervention group were participating in the walking program (compliance).

**Statistical analysis**

Demographic data were analyzed by descriptive analysis. Multivariate analysis of variance was conducted to examine differences in demographic variables (age, height, pre-pregnancy weight, pre-pregnancy BMI, education, employment, race, marital status, total household income, parity) between the groups. Two-way analysis of variance (ANOVA) was used to determine the differences in total steps per day (average steps/day), average minutes of meaningful walk (min/week), total GWG (kg), rate of GWG during M2M (kg/week), average dietary intake (kcal or g/day), birth weight (g), gestational length at delivery (week), birth weight z-score, and APGAR score (min) by treatment group and pre-pregnancy BMI category. Absolute difference (diff) between groups was reported when there was significant difference. Pairwise comparison tests (all pairs Tukey-Kramer \( p = 0.05 \)) were then performed to further determine the differences among overweight women in
the intervention group (Int-OW), overweight women in the control group (Con-OW), obese women in the intervention group (Int-OB), and obese women in the control group (Con-OB) on the aforementioned variables. Fisher’s exact tests were used to analyze differences in meeting 2009 IOM GWG recommendations, pregnancy complications, and infant outcomes among Int-OW, Con-OW, Int-OB and Con-OB women. All moderately intense cadences (≥80 steps/min) taken by participants for any bout length at each gestational data collection time point were visualized graphically (Matlab, Mathworks, Natick, MA). The Kolmogorov-Smirnov test was used to compare the probability distribution of the bouts of moderately intense cadence between the intervention and control groups by pre-pregnancy BMI category. Significance was defined as $P < 0.05$. Results are presented as mean ± standard deviation (mean ± SD). Data analyses were conducted using JMP, Version 7 (SAS Institute Inc., Cary, NC).

Results

**Participant characteristics**

Participant characteristics in each group by treatment and BMI category are presented in Table 1. Multivariate analysis of variance showed there were no significant differences between groups for age, height, gestational length at V1, education, employment, race, marital status, total household income, and parity. Pre-pregnancy weight and pre-pregnancy BMI were significantly different between overweight and obese participants. Overall, participants in the study were predominantly married, educated, and Caucasian.

**Objectively measured step counts using StepWatch™**
Number of participants who provided at least 3 valid days of data at each gestational
time point was as followed: V1 (n = 31), V2 (n = 36), V3 (n = 35), and V4 (n = 35).
Participant’s files that were not included in the final analysis were mainly due to missing
data, and misplacement of the monitor by the participants. Overall, participants in this study
were compliant in wearing the PA monitor. Participant’s files, which were included in the
final PA analysis, had on average 6 days of data at each gestational data collection time
point. Statistical analysis showed that there was no significant difference in participant’s
compliance among the groups (Int-OW, Con-OW, Int-OB, Con-OB).

**Walking amount: total steps per day**

At V1 (baseline) and V2, there was no significant difference between the treatment
groups, pre-pregnancy BMI category, or interaction effect in total steps per day (F = 1.049, p
= 0.387 for V1; F = 0.834, p = 0.485 for V2). At V3, there was a significant difference
between the pre-pregnancy BMI category (OW = 10016 steps; OB = 7931 steps; diff = 2130
steps; p = 0.011), but not the treatment groups or interaction effect in total steps per day (F =
3.227, p = 0.036). It was the same for V4, there was a significant difference between the pre-
pregnancy BMI category (OW = 8703 steps; OB = 7036; diff = 1667; p = 0.025), but not the
treatment groups or interaction effect in total steps per day (F = 2.519, p = 0.076). Pairwise
comparison tests showed that only Int-OW vs. Int-OB at V3 was significant different, but
not for the rest of the visits among the groups (Table 2).

**Walking intensity: moderately intense cadence**

Walking intensity characteristics of the women were determined using cadence
(steps/min). Cadence ≥80 steps/min was considered a moderately intense cadence; therefore,
any wear times that had ≥80 steps/min were extracted. Figure 2 shows the length of time
spent walking at cadence $\geq 80$ steps/min, shown by color intensity, separated into bouts of lengths (x-axis). This demonstrates the distribution pattern of lengths of bouts of moderately intense walking that woman achieved while under observation. At V1, the Kolmogorov-Smirnov test showed no significant difference between the distributions of cadence $\geq 80$ steps/min among the intervention and control groups for obese women, but there was a trend of significance difference between intervention and control for the overweight women. At V2, there was a significantly higher amount of cadence $\geq 80$ steps/min in the intervention group for both overweight ($p < 0.0001$) and obese ($p < 0.025$) women. At V3, overweight women in the intervention group had significantly more cadence $\geq 80$ steps/min than the control group ($p < 0.0001$); a trend of significance was observed among obese women ($p = 0.072$). At V4, there was a significantly higher amount of cadence $\geq 80$ steps/min in the intervention group for both overweight ($p < 0.0001$) and obese ($p < 0.025$) women. In addition, overweight women in the intervention group at V3 ($p < 0.01$) and V4 ($p < 0.005$) had a significantly higher amount of cadence $\geq 80$ steps/min than obese women in the same treatment.

**Meaningful walks: moderately intense cadence for at least eight minutes**

Any moderately intense cadences taken for at least 8 min in length of bout were further extracted to identify the amount (minutes) of meaningful walks taken by the participants. In other words, any time spent walking at cadence $\geq 80$ steps/min after the 8 minutes mark shown in Figure 2 would be considered as meaningful walks. Generally, there were higher percentages of overweight and obese women in the control group who had no minutes of meaningful walk across pregnancy (Table 2). When the average minutes of meaningful walks was examined using two way ANOVA, there was no significant
difference between the treatment groups, pre-pregnancy BMI category, or interaction effect at V1 (F = 0.954, p = 0.428). At V2, there were strong trends of significance for both treatment group (Int = 52.8 min; Con = 20.2 min; diff = 32.6; p = 0.054) and interaction effect (p = 0.066), but not pre-pregnancy BMI category (F = 2.983, p = 0.046). At V3, significant differences were observed between the treatment group (Int = 44.9 min; Con = 7.8 min; diff = 37.1 min; p = 0.01), pre-pregnancy BMI (OW = 45.8 min; OB = 6.9 min; diff = 38.9 min; p = 0.007) and interaction effect (p = 0.002) (F = 7.556, p < 0.001). At V4, treatment group (Int = 42.1 min; Con = 6.7 min; diff = 35.4 min; p = 0.014) and pre-pregnancy BMI (OW = 41.7 min; OB = 7.1 min; diff = 34.6 min; p = 0.016) were significantly different, but not interaction effect (F = 5.341, p = 0.004). Table 2 shows the pairwise comparison tests for all four groups of participants at each gestational time point.

**Gestational weight gain**

There was no significant difference in total GWG (F = 0.253, p = 0.859) or rate of GWG during M2M (kg/week) (F = 0.428, p = 0.734) among the women in the intervention group compared to the women in the control group for both pre-pregnancy BMI categories (Table 2). However, it appeared that overweight women in the intervention group were more likely to gain within the 2009 IOM recommendations compared to the control group, according to the Fisher’s exact test (p = 0.163) (Table 3).

**Dietary intake**

Number of participants who provided complete 3-days of data at each gestational time point was as followed: V1 (n = 37), V2 (n = 37), V3 (n = 36), and V4 (n = 36). Participants who had incomplete data were due to underreporting (n = 1) and preterm delivery (n = 1). When diet data were analyzed for each gestational data collection time
point, there was no significant difference between the groups for calories, carbohydrates, protein and total fat intake. Individual data was then combined across pregnancy to provide an overall average of dietary intake: calories (Int-OW = 2325.3 ± 509.6 kcal/day, Con-OW = 1915.1 ± 308.6, Int-OB = 2094.3 ± 397.6, Con-OB = 2187.9 ± 757.3; \( p = 0.380 \)), carbohydrates (Int-OW = 300.5 ± 63.2 g/day, Con-OW = 248.5 ± 50.8, Int-OB = 275.3 ± 46.1, Con-OB = 288.3 ± 91.0; \( p = 0.558 \)), protein (Int-OW = 89.0 ± 17.1 g/day, Con-OW = 78.3 ± 13.8, Int-OB = 81.3 ± 14.3, Con-OB = 88.8 ± 29.9; \( p = 0.351 \)), and total fat (Int-OW = 90.6 ± 27.1 g/day, Con-OW = 70.9 ± 16.9, Int-OB = 78.7 ± 21.3, Con-OB = 78.7 ± 36.0; \( p = 0.446 \)).

**Pregnancy complications and infant outcomes**

There were no significant differences in pregnancy complications and infant outcomes among all four groups of women (Table 3). A lower birth weight z-score (\( p = 0.239 \)) and lower risk of macrosomia (\( p = 0.335 \)) were observed among obese women who were in the intervention group compared to the control group; however, there was not a significant difference between the groups (Int-OB: birth weight z-score = 0.46 ± 0.99; macrosomia: 22.2%; Con-OB: birth weight z-score = 1.09 ± 1.19, macrosomia: 55.6%).

**Discussion**

One of the objectives of the current intervention was to help previously non-exercising, overweight and obese pregnant women to increase their moderate PA participation during pregnancy via walking. Our hypothesis was that previously non-exercising, overweight and obese women could increase moderate PA participation during pregnancy via a walking intervention. The results of the study showed that women in the intervention group were able to significantly increase their moderately intense cadence as
defined in the study especially among the overweight women. In fact, there were overweight women in the intervention group who met the minimum recommendation of 150 minutes per week of moderate PA (n = 2 at V2, n = 3 at V3, n = 2 at V4); however, none of the overweight women in the control group met the recommendation. Additionally, when at least 8 minute bouts of moderately PA were examined, women in the intervention group had more minutes of meaningful walks than control group. This was especially true among the overweight women after the intervention was introduced. On the contrary, more than 50% of the overweight and obese women in the control group had zero minutes of meaningful walks across pregnancy. Perhaps, the current intervention was successful in helping pregnant women increase their moderate PA participation during pregnancy particularly the overweight women.

Overall, the amount of moderately PA engaged by the overweight and obese women in the current intervention was substantially higher than other reported current PA trends among pregnant and non-pregnant populations. When prenatal PA participation was objectively measured using an ActiGraph accelerometer in the NHANES 2003 – 2006 cross-sectional data (n = 359) (21), the data showed that pregnant women only participated in an average of 12.0 ± 0.86 minutes/day of moderate activity and 0.3 ± 0.08 minutes/day of vigorous activity. When cadence of non-pregnant populations were examined by Tudor Locke et al. using the 2005 – 2006 NHANES data (n = 1963 females), women only accumulated 12.78 minutes/day of cadence ≥ 80 steps/min (55). Furthermore, it has been well documented that PA participation decreases as pregnancy progresses (42). It was reported by Evenson and colleagues that U.S. pregnant women spent 11.5 minutes/day during the first trimester, 14.3 minutes/day during the second trimester, and 7.6 minutes/day
during the third trimester in moderate to vigorous PA (21). In the current study, overweight women in the intervention group successfully maintained their duration of moderately intense walking throughout pregnancy, even during the late third trimester when step counts were monitored by StepWatch™.

Both the PA recommendations by ACOG 2002 and 2008 Physical Activity Guidelines for Americans prescribe moderate PA for the pregnant women. These guidelines are supported by evidence that shows moderately intense activities are identified with substantial health benefits among the non-pregnant population (43). Due to the growth of fetal tissue, the elevated basal metabolic rate and the increased energy cost of moving a heavier body, women may select less demanding activities and reduce the pace of those activities (44). Studies have demonstrated that pregnant women walk at a slower pace as pregnancy progresses and when walking pace among pregnant women is compared with a non-pregnant population (17, 29, 45). Therefore, even though the current intervention did not significantly increase the total steps per day taken (amount) by the women between the groups, it was successful in changing the intensity of the steps taken by the overweight and obese women in the intervention group. These women walked at a higher intensity and were, most importantly, able to sustain these habits until late pregnancy.

We further hypothesized that those participants who increased their moderate PA participation via the walking intervention would have more favorable GWG outcomes. Overall, the rate of GWG throughout the study between intervention and control groups for both overweight and obese women were not significantly different. When percentage of participants meeting 2009 IOM GWG guidelines was examined at V4, greater proportion of overweight women in the intervention group gaining within the recommendations, even
though it was not statistically significant (55.6 % among Int-OW vs. 20 % among Con-OW, \( p = 0.163 \)). The findings of the present study are supported by a meta-analysis conducted by Streuling and colleagues, which evaluated trials that only involved increased PA as the means to minimize GWG (51). Twelve RCTs were included in this analysis with interventions varying by intensity, duration, and mode of activity. Seven of the trials reported a trend for lowering GWG in the intervention group, one trial showed significant reductions in GWG, and five trials showed no significant effect on GWG. When all RCTs were combined on a scale, the overall meta-analysis finding demonstrated that PA modification resulted in significant GWG reduction (mean difference of -0.61; 95% CI: -1.17 – -0.06, \( p = 0.03 \)). The walking program of the current study significantly increased the moderately intense steps of women in the intervention group especially the overweight women during their pregnancy; therefore, the trend of a higher percentage of women in Int-OW group meeting the GWG guidelines may be partly explained by the increased moderate PA during pregnancy.

Our final hypothesis was that those participants who increased their moderate PA participation via the walking intervention would have more favorable birth outcomes. The walking program in this study did not cause any adverse effects on labor/delivery complications and birth outcomes. In fact, there was a trend for obese women who participated in the walking program to have lower infant birth weight z-scores and decreased odds of fetal macrosomia compared to obese women in the control group. In recent years, evidence shows that maternal PA participation increases the likelihood of giving birth to appropriate-for-gestational-age (AGA) infants. Most importantly, maternal PA helped reduce the risk of giving birth to LGA infants by not increasing the odds for a SGA infant
In a large cohort observational study (n = 79,692), Juhl et al. found that the longer the amount of time (h/week) women spent in PA participation during pregnancy, the lower the risk of delivering LGA infants; however, the intensity of the workout regimen was not mentioned in this study. In two smaller cohorts of observational studies, women who participated in at least 120 min/week of at least moderate PA during pregnancy had a significantly lower risk of delivering a LGA infant without increasing the risk for a SGA infant (3, 33). Thus, since the obese women in the intervention group significantly increased their moderately intense cadence after joining the walking program, a trend of increased in favorable child outcomes observed in the study may be explained by this positive change.

Walking is a common and popular choice of PA during pregnancy (30, 39). In observational studies, walking at a brisk pace has been shown to reduce the risk of gestational diabetes (62), pre-eclampsia (48), excessive GWG (52), and macrosomia (38). Mottola et al. conducted a case-controlled trial to assess the impact of combined energy restriction and a walking program on prevention of excessive weight gain in overweight Canadian pregnant women (NELIP) (31). The walking program was individualized to reach 30% peak heart rate (HR) reserve of the participant, and it was performed three to four times a week (40 min per session). Mottola et al. observed a significant increase in average daily step counts from the baseline value of 5677.6 ± 1738.0 steps to more than 10,000 steps per day. This study also resulted in 80% of the participants meeting the 2009 IOM weight gain recommendations on NELIP. To our knowledge, the current intervention was the first pilot randomized-controlled trial to help previously non-exercising, overweight and obese women increase moderate PA participation via walking. Different from the NELIP study, the present intervention was a PA-only intervention. Diet counseling was not provided nor was
caloric restriction emphasized in the study. As a result, any positive maternal and child health outcomes observed in the study would be primarily attributed to the increased PA participation during pregnancy. Interestingly, diet data was collected at each visit in this study, and the results showed no significant difference between the treatment groups in total calories, carbohydrate, protein and total fat intake.

Little information is available about the feasibility and benefits of previously non-exercising overweight and obese pregnant women increasing their moderate physical activity, via walking. Therefore, this intervention added unique contributions in the field of maternal and child health. This is the first study to objectively measure walking cadence/intensity of pregnant women in order to evaluate PA participation and patterns during pregnancy in a randomized-controlled trial. The current trial was an unsupervised, free-living walking program. The women were provided with a treadmill for home use. Thus far, the majority of successful interventions that have targeted overweight and obese pregnant women consist of fully or partially supervised activities (4, 15, 31). The current intervention was the first to help pregnant women increase moderate PA participation by providing a tool for home use, without direct supervision. A treadmill could be a relatively cost-effective intervention tool compared to other interventions, which require trained staff members to supervise the workout sessions. In addition, since walking is the most common activity practiced among pregnant women, being able to objectively measure step counts and use the cadence to determine activity intensity could provide further insight into the relationship between PA participation during pregnancy and health outcomes of the mother and fetus. In recent years, the use of cadence in intervention and behavioral research has been promoted due to its easily interpretable results (57).
It is acknowledged that the present study has some limitations. A major limitation of the current study is its small sample size and high variability among the groups. These factors could potentially reduce the ability to detect statistically significant effects of the intervention. Secondly, there is no known study that has been conducted to measure the walking cadence/intensity of the pregnant population. As a result, the present study has utilized the evidence in the literature to define the moderately intense cadence for pregnant women, which was a cadence ≥ 80 steps/min of the participants. Further research in this area is needed. Thirdly, self-reported pre-pregnancy BMI was used in the study, which could lead to inaccurate data because evidence has shown that overweight women are more likely to underreport their weight compared to normal or underweight women (47). Fourth, research has shown that seasonal changes and weather can have an effect on PA participation (54). The current intervention was a longitudinal study and women were enrolled for a minimum of 20 weeks and were thus enrolled over 2 different seasons. In future studies, environmental variables that may support or hinder PA participation should be taken into consideration. Lastly, the StepWatch™ monitor may not have accounted for other activities the women participated in during the intervention period, such as running, biking or swimming. Considering that the intervention was focused on walking, the StepWatch™ monitor was viewed as an acceptable measurement tool for quantifying the intervention effect.

In conclusion, the current intervention changed the walking intensity of all women enrolled in the intervention group during pregnancy. Even though it was not statistically significant, there was a trend for women in the intervention group to have more favorable pregnancy and birth outcomes compared to the control group. The findings of the present
study provide preliminary results in understanding walking patterns during pregnancy and
health outcomes of the mother and baby. Since the study of the relationship between
cadence and one’s free-living patterns of ambulatory activity is a new and innovative area,
future research is needed to examine the relationship between mother’s cadence intensity
and pregnancy outcomes.

References

1. ACOG Committee Obstetric Practice. ACOG committee opinion: exercise during

2. Adamo KB, Ferraro ZM, Brett KE. Can we modify the intrauterine environment to
halt the intergenerational cycle of obesity? Int J Environ Res Public Health

3. Alderman BW, Zhao H, Holt VL, Watts DH, Beresford SAA. Maternal physical

4. Artal R, Catanzaro RB, Gavard JA, Mostello DJ, Friganza JC. A lifestyle intervention
of weight-gain restriction: diet and exercise in obese women with gestational diabetes

5. Asbee SM, Jenkins TR, Butler JR, White J, Elliot M, Rutledge A. Preventing
excessive weight gain during pregnancy through dietary and lifestyle counseling.

index on pregnancy outcomes in nulliparous women delivering singleton babies
[Internet]. BMC Public Health 2007;7(168)[cited 2012 Nov 19] Available from:
z&rendertype=abstract

7. Brown WJ, Trost SG. Life transitions and changing physical activity patterns in

8. Campbell CG, Foster RC, Lanningham-Foster LM, Smith KM. The modified
obstetric metabolic equivalent (MET): finding a MET that fits in pregnancy
[Internet]. J DOHaD 2012;3(3):159–65.[cited 2013 Apr 11] Available from:
http://www.journals.cambridge.org/abstract_S2040174412000025


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<th>Variable</th>
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<td>Overweight</td>
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<td>94.8 ± 14.4</td>
</tr>
<tr>
<td>Pre-pregnancy BMI* (kg/m²)</td>
<td>26.5 ± 1.2</td>
<td>34.7 ± 4.6</td>
</tr>
<tr>
<td>Gestational length at V1 (weeks)</td>
<td>12.6 ± 1.3</td>
<td>12.3 ± 0.8</td>
</tr>
<tr>
<td>Employment (n)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Full time ≥ 40 hours</td>
<td>2</td>
<td>5</td>
</tr>
<tr>
<td>Part time &lt; 40 hours</td>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td>Non-employed = 0 hours</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>Total household Income (n)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>&lt; $25 000</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>$25 000 to $50 000</td>
<td>6</td>
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<tr>
<td>$50 000 to $75 000</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>&gt; $75 000</td>
<td>1</td>
<td>4</td>
</tr>
<tr>
<td>Nulliparas* (n)</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Paras ≥ 1 b (n)</td>
<td>6</td>
<td>6</td>
</tr>
</tbody>
</table>

Values shown are mean ± SD, unless otherwise noted (n).

*pre-pregnancy weight and BMI significantly different between overweight and obese women

Nulliparas refers to first-time pregnant women
Paras ≥ 1 refers to women with at least one pregnancy
Table 2: Physical activity outcome measures by treatment group and pre-pregnancy BMI category

<table>
<thead>
<tr>
<th>Variables</th>
<th>Overweight</th>
<th>Overweight</th>
<th>Obese</th>
<th>Obese</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Intervention (n = 9)</td>
<td>Control (n = 10)</td>
<td>Intervention (n = 9)</td>
<td>Control (n = 9)</td>
</tr>
<tr>
<td>Total steps (steps/day)</td>
<td>V1</td>
<td>8534 ± 2104</td>
<td>7964 ± 2300</td>
<td>7737 ± 1693</td>
</tr>
<tr>
<td></td>
<td>V2</td>
<td>9346 ± 1826</td>
<td>8496 ± 2104</td>
<td>7751 ± 2065</td>
</tr>
<tr>
<td></td>
<td>V3</td>
<td>10912 ± 1582</td>
<td>3040</td>
<td>7867 ± 1475</td>
</tr>
<tr>
<td></td>
<td>V4</td>
<td>9327 ± 1976</td>
<td>8078 ± 2378</td>
<td>7416 ± 1439</td>
</tr>
<tr>
<td>Participants with no min of meaningful walk (%)</td>
<td>V1</td>
<td>37.5</td>
<td>50.0</td>
<td>62.5</td>
</tr>
<tr>
<td></td>
<td>V2</td>
<td>11.1</td>
<td>60.0</td>
<td>44.4</td>
</tr>
<tr>
<td></td>
<td>V3</td>
<td>22.2</td>
<td>60.0</td>
<td>50.0</td>
</tr>
<tr>
<td></td>
<td>V4</td>
<td>33.3</td>
<td>60.0</td>
<td>62.5</td>
</tr>
<tr>
<td>Average min of meaningful walks (min/week) *</td>
<td>V1</td>
<td>23.3 ± 26.7</td>
<td>11.9 ± 18.6</td>
<td>6.5 ± 10.5</td>
</tr>
<tr>
<td></td>
<td>V2</td>
<td>76.7 ± 51.1</td>
<td>13.2 ± 25.6</td>
<td>28.9 ± 37.2</td>
</tr>
<tr>
<td></td>
<td>V3</td>
<td>81.3 ± 75.4</td>
<td>10.2 ± 14.1</td>
<td>8.4 ± 11.1</td>
</tr>
<tr>
<td></td>
<td>V4</td>
<td>70.1 ± 68.5</td>
<td>13.3 ± 22.6</td>
<td>14.1 ± 32.6</td>
</tr>
</tbody>
</table>

Values shown are mean ± SD

* meaningful walks = moderately intense walk (≥ 80 steps/min) in bout of at least 8 consecutive minutes

Different letters indicate significant differences (all pairs Tukey-Kramer p = 0.05)

V1 = weeks 10 - 14 of gestation; V2 = weeks 17 - 19 of gestation; V3 = weeks 27 - 29 of gestation; V4 = weeks 34 - 36 of gestation; GWG = gestational weight gain; M2M = Moms to Move study
Table 3: Pregnancy and infant outcomes by treatment group and pre-pregnancy BMI category

<table>
<thead>
<tr>
<th>Variables</th>
<th>Overweight</th>
<th>Obese</th>
<th>Overweight</th>
<th>Obese</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Intervention (n = 9)</td>
<td>Control (n = 9)</td>
<td>Intervention (n = 9)</td>
<td>Control (n = 10)</td>
</tr>
<tr>
<td>Weekly GWG during M2M (kg/wk)</td>
<td>0.5 ± 0.18</td>
<td>0.39 ± 0.16</td>
<td>0.47 ± 0.33</td>
<td>0.48 ± 0.30</td>
</tr>
<tr>
<td>Total GWG (kg)</td>
<td>10.53 ± 5.37</td>
<td>9.94 ± 6.14</td>
<td>12.07 ± 9.01</td>
<td>12.48 ± 8.51</td>
</tr>
<tr>
<td>Meeting 2009 IOM guidelines</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Exceeded IOM (%)</td>
<td>44.4</td>
<td>50.0</td>
<td>77.8</td>
<td>77.8</td>
</tr>
<tr>
<td>Within IOM (%)</td>
<td>55.6</td>
<td>20.0</td>
<td>0.0</td>
<td>11.1</td>
</tr>
<tr>
<td>Below IOM (%)</td>
<td>0.0</td>
<td>30.0</td>
<td>22.2</td>
<td>11.1</td>
</tr>
<tr>
<td>Birth weight (g)</td>
<td>3.76 ± 0.44</td>
<td>3.59 ± 0.46</td>
<td>3.54 ± 0.51</td>
<td>3.94 ± 0.48</td>
</tr>
<tr>
<td>Gestational length at delivery (week)</td>
<td>39.7 ± 0.7</td>
<td>39.2 ± 1.6</td>
<td>39.0 ± 1.2</td>
<td>39.7 ± 0.7</td>
</tr>
<tr>
<td>Birth weight z-score</td>
<td>0.68 ± 0.94</td>
<td>0.54 ± 0.67</td>
<td>0.46 ± 0.99</td>
<td>1.09 ± 1.19</td>
</tr>
<tr>
<td>Low birth weight &lt; 2500 g (n)</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Macrosomia &gt; 4000 g (n)</td>
<td>3</td>
<td>1</td>
<td>2</td>
<td>5</td>
</tr>
<tr>
<td>APGAR score</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 min</td>
<td>7.9 ± 0.6</td>
<td>8.1 ± 0.9</td>
<td>8.0 ± 0.9</td>
<td>7.3 ± 1.8</td>
</tr>
<tr>
<td>5 min</td>
<td>8.9 ± 0.6</td>
<td>8.6 ± 1.0</td>
<td>8.6 ± 0.7</td>
<td>8.4 ± 1.8</td>
</tr>
<tr>
<td>Pregnancy complications</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Preterm delivery, &lt;37 week (n)</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Cesarean delivery (n)</td>
<td>0</td>
<td>4</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>Pre-eclampsia (n)</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Maternal hypertension (n)</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Gestational diabetes (n)</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

Values shown are mean ± SD, unless otherwise noted % or n
**Figure 1:** Participant flow chart

**Figure 2:** Walking bouts distribution for each participant in the intervention and control groups. All bouts of walking at cadence ≥80 steps/min are shown for all participants at each gestational data collection time point. Each segment on the Y-axis across the panel represents a week’s worth of step count data for a single participant. All participants are represented in the same order on the 4 panels, across measurement periods. The length of time spent walking at cadence >=80 steps/min, shown by color intensity, separated into bouts of lengths given on the x-axis. Bouts after dotted lines (at 8 minute mark) represent meaningful walking. (OW- overweight women; OB- obese women; V1 = weeks 10 – 14 of gestation; V2 = weeks 17 – 19 of gestation; V3 = weeks 27 – 29 of gestation; V4 = weeks 34 – 36 of gestation).

**Figure 3:** Overweight and obese pregnant women who met the 2009 IOM gestational weight gain recommendations at the last study visit (V4).
Figure 1: Participant flow chart
Figure 2: Walking bouts distribution for each participant in the intervention and control groups.
**Figure 3:** Overweight and obese pregnant women who met the 2009 IOM gestational weight gain recommendations at the last study visit (V4).
CHAPTER 4: OBJECTIVELY MEASURED STEP COUNT CAN BE PREDICTED BY SELF-EFFICACY AND PRE-PREGNANCY BMI AMONG OVERWEIGHT AND OBESE PREGNANT WOMEN IN A RANDOMIZED-CONTROLLED TRIAL

A paper has been submitted to the International Journal of Behavioral Nutrition and Physical Activity

*Kai Ling Kong, Amy S Welch, Christina G Campbell, Anna D Peterson, Lorraine M Lanningham-Foster*

Abstract

**Background:** Research in understanding the relationship between self-efficacy and physical activity (PA) participation during pregnancy is limited. The purposes of this study were 1) to evaluate exercise self-efficacy of pregnant women in a walking intervention; 2) to examine the relative contribution of pre-pregnancy body mass index, barrier self-efficacy and task self-efficacy in predicting PA participation during pregnancy.

**Methods:** Thirty seven overweight or obese (BMI \( \geq 25.0 \text{ kg/m}^2 \)) pregnant women were randomly assigned to a walking intervention versus no-intervention control group. Exercise self-efficacy was assessed using barrier and task self-efficacy questionnaires, and PA participation was quantified by step counts using a StepWatch™ Activity Monitor. These assessments were performed at the end of the second (V3) and late third trimester (V4); while, self-reported pre-pregnancy BMI was obtained during enrollment. ANOVA was used to determine the differences in barrier and task self-efficacy between the groups. Linear and all-subsets regression analyses were used to identify the relative contribution of pre-pregnancy BMI, barrier and task self-efficacy to predict step count.
**Results:** Barrier self-efficacy was 13.3% and 15.2% higher in the intervention group compared to the control group at V3 and V4 respectively; while, task self-efficacy was 30.9% (V3) and 29.5% (V4) higher in the intervention group compared to the control group at both visits. At V3, task self-efficacy ($r^2 = 0.254, p < 0.003$) and barrier self-efficacy ($r^2 = 0.123, p < 0.049$) independently predicted step count; however task self-efficacy together with pre-pregnancy BMI explained 30.0% ($p < 0.006$) of the variance, which was selected as the best model to predict step count. At V4, task self-efficacy ($r^2 = 0.234, p < 0.003$) and pre-pregnancy BMI ($r^2 = 0.167, p < 0.015$) independently predicted step count, and both variables combined explained 35.9% of the variance ($p < 0.001$), which was selected as the best model to predict step count.

**Conclusions:** Interventions designed to increase self-efficacy might be effective to promote active lifestyles during pregnancy, especially later in gestation for women with higher pre-pregnancy BMI.

**Keywords:** Prenatal physical activity, Pregnancy, Step count, Barrier self-efficacy, Task self-efficacy

**Background**

Prenatal physical activity (PA) has become an important aspect within the field of maternal and child health due to the evidence of positive health outcomes of PA during pregnancy for the mother and fetus, such as the reduced risk of excessive gestational weight gain [1], preeclampsia [2], gestational diabetes [3], incidence of operative delivery [4], and low back pain [5]. According to Physical Activity Guidelines for Americans (PAG) in 2008, pregnant women who are healthy and without medical complications should engage in a minimum of 150 minutes of moderate-intensity activities spread throughout the week [6].
Moderate-intensity exercise is defined as an activity that expends 3.5-7 kcal/min, an intensity of 50-70% max heart rate, or is within the range of 3 to 6 metabolic equivalents of task (METs). In spite of these recommendations and the benefits of engaging in maternal PA, many pregnant women still do not meet the PA recommendations [7, 8]. Additionally, women who were active before becoming pregnant significantly decreased their PA participation during pregnancy [9]. This decline in PA participation is particularly common when pregnant women reach their third trimester, regardless of pre-pregnancy Body Mass Index (BMI) [8, 10]. With the prevalence of sedentary and low active lifestyles among pregnant women, interventions are needed to help women increase their PA participation.

Unfortunately, despite the consensus that intervention studies should be theoretically driven [11], there is an extremely limited number of interventions in this field that have been based on theoretical frameworks. In a recent meta-analysis, Gardner et al. only identified two interventions reporting the use of behavioral theories to inform intervention design [12]: one mentioned the use of social learning theory [13], and the other used precede-proceed and transtheoretical models [14]. However, neither of these papers included detail regarding how the theoretical constructs were used to develop the interventions. Ideally, correlates or predictors associated with positive behavioral modification should be identified before any intervention is designed or implemented. These correlates or predictors can potentially help with program adherence if they are targeted in the interventions [15]. Dropout rate for exercise programs is generally high in the non-pregnant population [11], thus the same if not, higher dropout rate among pregnant women due to the increased psychological and physical demands during pregnancy [16] might be expected. Numerous studies have examined the association of theory-based psychosocial factors in predicting PA participation.
during pregnancy according to a review by Gaston and Cramp [17]. These theory-based psychosocial factors were mainly taken from the Theory of Planned Behavior [16, 18–21], the socioecologic framework [22, 23], and the social cognitive theory variables [24]. Among these psychosocial factors, self-efficacy from the social cognitive theory has yielded the most consistent positive relationship with PA participation during pregnancy. Therefore, self-efficacy is clearly an important factor that needs to be targeted in behavioral interventions among the pregnant population [25].

Self-efficacy is the belief in one’s capabilities to put forth the necessary effort to overcome various challenges [26]. It influences the adoption, initiation, and maintenance of health behaviors such as leisure time PA participation [27, 28]. Studies have shown that self-efficacy is a strong correlate and determinant of PA among diverse populations including children, men, and non-pregnant women [29–33]. As a result, increasing pregnant women’s exercise self-efficacy could inevitably help to increase their maternal PA participation. In fact, when Hinton and Olson [34] examined the psychosocial predictors of pregnancy-related changes in PA participation, they concluded that exercise self-efficacy was a key predictor of PA participation during the perinatal period after controlling for age, pre-pregnancy BMI, and frequency of pre-pregnancy exercise. They also noted that pre-pregnancy BMI was a predictor of PA participation during pregnancy. Women who had higher pre-pregnancy BMI were predicted to be more active during pregnancy, which was contrary to other studies that showed a negative relationship between pre-pregnancy BMI and PA participation during pregnancy [35–37]. Further, Cramp and Bray [24] completed an observational study that supported the findings of Hinton and Olson. In this cross-sectional study, they demonstrated that exercise self-efficacy (barrier and task self-efficacy)
independently predicted leisure time PA participation across pregnancy (at week 18, 24, 30 and 35 of gestation). One limitation to these studies was the use of self-reported PA which is subject to social desirability bias and misreporting [38]. As a result, there is a need for an objective measure of PA when self-efficacy is measured prospectively among pregnant women in order to better understand the relationship of self-efficacy and PA participation during pregnancy.

Overall, it appears that both self-efficacy and pre-pregnancy BMI are important variables in understanding the PA behavior of pregnant women. Interventions have been designed to help women to increase their PA participation during pregnancy in order to improve maternal and fetal health outcomes [39–42], yet, to our knowledge, none of these studies has investigated the impact of their interventions on psychosocial outcomes, for example, exercise self-efficacy. Walking has been documented to be an appropriate and easily tolerated activity [43] and is one of the most frequent leisure activities performed by pregnant women [7, 36]. Therefore, the purpose of this study was 1) to compare exercise self-efficacy (barrier self-efficacy and task self-efficacy) of participants in a walking intervention versus non-intervention control group toward the end of a randomized controlled trial; 2) to examine the relative contribution of pre-pregnancy BMI, barrier self-efficacy and task self-efficacy in predicting step count at the end of second and late third trimesters of pregnancy using an objective measurement tool. Our hypotheses were 1) women in the walking intervention group would have higher barrier and task self-efficacy toward the end of the intervention; 2) pre-pregnancy BMI together with barrier and task self-efficacy would be a better predictor of step count at the end of second and late third trimester than any of the predictors independently.
Methods

Study Design

The Blossom Project team of Iowa State University conducted a pilot randomized controlled trial entitled ‘Moms to Move’ (M2M). The objectives of M2M study were 1) to increase PA participation among previously non-exercising, overweight and obese pregnant women to meet the PA recommendations of a minimum 150 minutes of moderate-intensity activities spread throughout the week, via walking; 2) and to evaluate the impacts of walking on gestational weight gain and birth weight of offspring when previously non-exercising, overweight and obese pregnant women meet the PA guidelines. The intervention in this study was a walking program. Women in the intervention group were advised to increase PA participation via walking to meet the minimum recommendation of 150 minutes per week of moderate intensity PA during pregnancy. They were also advised to spread their activities throughout the week, such as 30 minutes of walking five days per week [44]. They were allowed to walk in shorter bouts; however, they were advised to keep the bouts to at least 10 minutes in order to gain exercise benefits from their walk [45]. Women in the control group were not provided advice with respect to PA participation, but they were not restricted with any form of PA participation during pregnancy. Barrier self-efficacy, task self-efficacy and PA were measured at the end of the second trimester (weeks 27-28 of gestation) and the late third trimester (weeks 34-36 of gestation) of pregnancy. Self-reported pre-pregnancy BMI was obtained during enrollment.

Participants

Participant recruitment occurred from January 2011 to March 2012 through emails, online advertisements, and fliers posted in the community and at local obstetric clinics.
Participants met the following inclusion criteria: prior to week 15 of gestation, maternal age between 18-45 years old, singleton pregnancy, non-smoker, self-reported overweight (BMI \( \geq 25.0 \text{ kg/m}^2 \)) or obese (BMI \( \geq 30.0 \text{ kg/m}^2 \)) prior to pregnancy, no history of chronic diseases (including type 1 diabetes, cardiovascular disease, thyroid disorder or lung disorder), and no history of gestational diabetes. In addition, only non-exercising women (less than three times per week of leisure time PA participation at 30 minutes or more per session) for at least six months preceding their enrollment into the study were recruited. Gestational length was calculated based on the self-reported date of the participants’ last normal menstrual cycle or the due date determined by the medical provider using ultrasound.

Potential participants who expressed interest were screened for qualification criteria. Each participant was provided with an informed consent document for review. The study was approved by the Institutional Review Board of a large, mid-western university. Forty-six pregnant women enrolled in the study. The final number of women who completed the protocol was 37 (n = 18 participants in the intervention; n = 19 participants in the control). Five women withdrew from the study due to time conflicts and four women experienced pregnancy-related complications unrelated to study, such as miscarriage. Mean ages of participants in each group were 27.4 ± 1.0 years old (intervention group) and 26.5 ± 0.7 years old (control group).

**Procedure**

Participants who qualified through email screening were invited for an enrollment appointment prior to week 15 of gestation. During the enrollment, participants signed the consent form, filled out a medical history questionnaire and provided contact details of their
medical providers. Approvals for participation in the study were obtained from medical providers of the women. Height and weight were measured during this first visit. Participants were then randomly assigned to either the intervention or control condition. Randomization was conducted using a computer-based random number generator (Microsoft Excel 2010, WA). All participants reported to the clinical research center at each of the following time points: weeks 10-14 (V1), 17-19 (V2), 27-29 (V3), and 34-36 (V4) of gestation. Following the completion of the questionnaires, women were provided an ankle-worn pedometer, StepWatch™ Activity Monitor (OrthoCare Innovations, LLC, Oklahoma City, Oklahoma). This pedometer allowed monitoring of the average daily step count of women during the preceding week for a total of seven days.

The walking intervention began no earlier than week 12 and no later than week 15 of gestation and lasted until at least week 35. Walking could occur indoors, such as walking at the mall or outdoors, such as walking at the park. To encourage the participants in the intervention group to achieve their walking goal, treadmills were provided to the participants to use in their homes for the duration of the study. Treadmills were returned following the completion of the walking intervention. Participants in the control group were not given treadmills for home use during the study.

Data Collection

Anthropometric and demographic data.

Height and weight were measured at each gestational time point visit. Height was measured to the nearest 0.1 cm (Ayrton 226 Hite-Rite Precision Mechanical Stadiometer, Quick Medical GS, Snoqualmie, WA) and weight was measured to the nearest 0.1 kg (Detecto Model 6855 Cardinal Scale, Manufacturing Co., Webb City, MO). Pre-pregnancy
BMI was determined by using height measured at enrollment and woman’s self-reported weight prior to conception.

**Self-efficacy data.**

Exercise self-efficacy was examined from two perspectives (barrier and task) using questionnaires.

**Barrier self-efficacy.**

An open-and close-ended questionnaire was used to assess barriers to PA over the subsequent 6 weeks by participants [24, 46] at V3 and V4. Barriers were defined as “anything that may stop you from doing physical activity”. Participants were asked to list up to four barriers to PA that were relevant to them and were anticipated to occur in the next 6 weeks. Based on previous research [46] and to limit subject burden [24], the list of barriers was limited to four. For each barrier that was listed on the questionnaire, participants were asked to indicate their confidence to overcome that particular barrier should it occur in the next 6 weeks. Confidence was rated on a scale of 0% (absolutely not confident) to 100% (absolutely confident), using 10-point increments. The overall strength of the barrier self-efficacy was calculated by averaging the sum of the rated confidence of each barrier. The internal consistencies for this scale were high at each visit (Cronbach’s alpha = 0.873 at V3; Cronbach’s alpha = 0.829 at V4).

**Task self-efficacy.**

A 7-item questionnaire was used to assess participants’ confidence in their ability to walk for at least 30 minutes at their preferred pace on one day up to seven days in the subsequent week. Participants’ responses could range from 10% (lowest confidence) to 100% (highest confidence). Overall average task self-efficacy was calculated by summing
the scores for each item and dividing it by seven. This scale was developed in accordance with the guidelines for developing self-efficacy scales [47, 48]. The internal consistencies for this scale were high at each visit (Cronbach’s alpha = 0.941 at V3; Cronbach’s alpha = 0.944 at V4).

**Physical activity data: StepWatch™ Activity Monitor.**

Physical activity was monitored using the StepWatch™ Activity Monitor (SAM), an objective measurement tool, worn on the outer side of the right ankle for one week, 24 hours per day for 7 days. The SAM contains a microprocessor that uses a combination of acceleration, position, and timing to detect steps therefore, the outputs of the SAM are based on the amount, rate, and pattern of walking. It is calibrated to the individual’s height. In our study, the PA data was obtained after the collection of self-efficacy data at V3 and V4. PA participation was determined using step data (step counts) from the SAM.

**Data processing.**

Individual preliminary data files were examined graphically. Step count data was collected for consecutive 24 hours period for seven days. The excluded data in this study provided less than 300 consecutive minutes per day of wear time (step/min > 0) during her typical waking hours (i.e. 7 am to 10 pm). Only women recording at least three valid days of step count were included in the final PA analysis.

**Statistical Analysis**

Demographic data was analyzed by descriptive analysis. Multivariate analysis of variance was conducted to examine differences in demographic variables (age, height, pre-pregnancy weight, pre-pregnancy BMI, education, employment, race, marital status, total household income, parity) between the two groups. Two-way analysis of variance
(ANOVA) was used to determine the differences in barrier and task self-efficacy by treatment group and BMI category. Where there was significant difference between the groups, absolute difference (diff) would be reported. A Pearson correlation coefficient analysis was also conducted to examine the association between pre-pregnancy BMI, barrier and task self-efficacy. Linear regression analyses were conducted to determine if pre-pregnancy BMI, barrier, and task self-efficacy could independently predict step count at V3 and V4. All-subsets regression analyses were conducted to determine the best fit models for step count prediction at these two visits using the same variables. The top three best models based on the AIC values are shown in Table 3. Significance was defined as $P < 0.05$. Results are presented as mean ± standard deviation (mean ± SD). Data analyses were conducted using IBM SPSS Statistics, Version 19.0 (SPSS Inc., Armonk, NY) and JMP, Version 7 (SAS Institute Inc., Cary, NC).

**Results**

**Participant Characteristics**

Participant characteristics in each group by treatment and BMI category can be found in Chapter 3, Table 1. The mean age of overweight women in the intervention group (Int-OW) (n = 9) was 26.2 ± 2.6 years old; overweight women in the control (Con-OW) (n = 10) was 27.3 ± 3.6; obese women in the intervention group (Int-OB) (n = 9) was 28.6 ± 5.3; obese women in the control group (Con-OB) (n = 9) was 25.7 ± 4.0. Multivariate analysis of variance showed there were no significant differences between groups for age, height, gestational length at V1, education, employment, race, marital status, total household income, and parity. Pre-pregnancy weight and pre-pregnancy BMI were significantly
different between overweight and obese participants. Overall, participants in the study were predominantly married, educated, and Caucasian.

**Comparison of Barrier and Task Self-Efficacy across Treatment Groups**

**Barrier self-efficacy.**

At V3, there was as strong trend of significant difference between the treatment group (Int = 70.3%; Con = 57.0%; diff = 13.3%; \( p = 0.077 \)), significant difference between the pre-pregnancy BMI (OW = 72.4%; OB = 54.9%; diff = 17.5%; \( p = 0.023 \)), but no interaction effect (\( F = 2.8911, p = 0.052 \)). At V4, there was a significant difference between the treatment groups (Int = 64.6%; Con = 49.4%; diff = 15.2%; \( p = 0.045 \)), but not pre-pregnancy BMI or interaction effect (\( F = 1.6607; p = 0.194 \)). In other words, barrier self-efficacy was 13.3% and 15.2% higher in the intervention group compared to the control group at V3 and V4 respectively (Figure 1).

**Task self-efficacy.**

At V3, there was a significant difference between the treatment group (Int = 78.2%; Con = 47.3%; diff = 30.9%; \( p < 0.0001 \)), pre-pregnancy BMI (OW = 70.6%; OB = 54.9%; diff = 15.7%; \( p < 0.006 \)), and a strong trend of significance for the interaction effect (\( p = 0.067 \)) (\( F = 14.932; p < 0.0001 \)). At V4, there was a significant difference between the treatment groups (Int = 73.7%; Con = 44.2%; diff = 29.5%; \( p < 0.0001 \)), but not BMI category or interaction effect (\( F = 6.6934; p = 0.001 \)). In short, task self-efficacy of women in the intervention group was 30.9% (V3) and 29.5% (V4) higher than the control group at both visits (Figure 2).

**Correlations and Step Count Prediction**
Table 1 shows that barrier and task self-efficacy were positively correlated with each other \((p < 0.0001)\) at both time points \((r = 0.585 \text{ at V3 and } r = 0.683 \text{ at V4})\). Linear regression analyses were conducted to determine if pre-pregnancy BMI, barrier, and task self-efficacy could independently predict the amount of steps taken by the women at V3 and V4 respectively. Table 2 shows that at V3, task self-efficacy \((p = 0.003)\) and barrier self-efficacy \((p = 0.049)\) independently predicted the amount of steps taken by the women. At V4, task self-efficacy \((p = 0.003)\) and pre-pregnancy BMI \((p = 0.015)\) independently predicted the amount of steps taken by the women. All-subsets regressions were then conducted to determine the best fit models to predict the PA participation of the women at each visit using three variables, pre-pregnancy BMI, barrier, and task self-efficacy. The top three best models based on the AIC values are listed in Table 2. At V3, the model that included task self-efficacy and pre-pregnancy BMI \(\left( r^2 \text{ of } 0.300, p = 0.006 \right)\) was selected as the best model for step count prediction due to its small root mean square error (RMSE) and AIC value. At V4, task self-efficacy and pre-pregnancy BMI \(\left( r^2 \text{ of } 0.359, p = 0.001 \right)\) provided the best model for the step count prediction (with the smallest corresponding RMSE and AIC).

**Discussion**

The findings of this study demonstrated that pregnant women in a walking intervention, which started at the beginning of the second trimester (weeks 12-15 of gestation) had a higher barrier and task self-efficacy at the end of second (V3) and late third trimester (V4). In the past, many outcome measures of lifestyle interventions in pregnancy have focused on health outcomes of their participants, such as interventions designed to increase PA participation to limit excessive gestational weight gain [39–42]. However, no
such studies have assessed the impact of these interventions on psychosocial outcomes of the participants. Even though the present intervention was not designed to change the self-efficacy of participants, women in the intervention group had a higher perceived capability to overcome barriers and a higher confidence in carrying out the task of walking for at least 30 minutes at their preferred pace for the upcoming week at the end of second trimester and late third trimester compared with women in the control group. This observed higher self-efficacy among women in the intervention group could be due to the treadmill available at home. In studies conducted by Leiferman et al. [23], and Evenson et al.[22], environmental factors such as the weather (too hot or too cold), ability to access recreational facilities, as well as care giving duties were some of the reported barriers to not being physically active during pregnancy. Therefore, having a treadmill at home could potentially help women to overcome some of these perceived barriers.

Additionally, women in the intervention group were also given advice to perform shorter bouts of walking (at least 10 min) to meet the 30 minutes of walking on most days of the week for a minimum of 150 minutes per week of moderate physical activity recommendation. Prenatal PA participation decreases progressively with gestation [7, 8, 49]. This decrease in PA participation could be due to physical and physiological changes, such as heavier body weight due to the growing stomach and water retention especially toward the end of the pregnancy. Therefore, smaller bouts of exercise might be more feasible to the pregnant women, which explained the higher self-efficacy among women in the intervention group compared to control group.

Using linear regression analyses, the present study was able to show that task self-efficacy and barrier self-efficacy independently predicted the amount of steps taken by the
women at the end of the second trimester (V3). At late third trimester (V4), both task self-efficacy and pre-pregnancy BMI independently predicted the step count. The result of the present study, which was the first to use an objective measure of PA, was supported by Cramp and Bray’s previous work using self-reported PA measure [24]. In their observational study, they found that across pregnancy (at week 18, 24, 30 and 35 of gestation), both barrier and task self-efficacy independently predicted self-report leisure time PA participation. The finding that pre-pregnancy BMI influenced step count prediction is in agreement with two other studies, which showed that the greater the pre-pregnancy BMI, the higher the likelihood of women dropping out from sports involvement or any form of structured exercise programs after becoming pregnant [36, 37]. However, Hinton and Olson conducted an observational study to examine changes in PA levels during pregnancy and found that higher pre-pregnancy BMI predicted higher PA level from pre-pregnancy to pregnancy [34]. They suggested that their findings were not a result of sedentary women with higher pre-pregnancy BMI becoming more physically active in pregnancy, but physically active women of lower pre-pregnancy BMI decreased their PA level significantly during pregnancy.

Additionally, in the current study, both task self-efficacy and pre-pregnancy BMI were selected as the best model to predict step counts at the end of second trimester and late third trimester. The all-subsets analysis showed that at V3, task self-efficacy together with pre-pregnancy BMI explained 30% of the variance in step count prediction; while at V4, task self-efficacy together with pre-pregnancy BMI explained 36% of the variance. As a result, even though barrier self-efficacy showed moderate to significant predictive magnitude according to the linear regression analyses, task self-efficacy and pre-pregnancy
BMI emerged as the major contributors to the prediction at both time points. In other words, task self-efficacy and pre-pregnancy BMI were the most proximal determinants of PA participation for overweight and obese pregnant women during pregnancy.

The findings of this study concur with other studies, which have shown the dominant effect of task self-efficacy in PA prediction both in pregnant [24], as well as non-pregnant [46] populations. Similar to the results of Cramp and Bray’s study [24], the present study also observed a considerably large variance shared by barrier self-efficacy and task self-efficacy according to the correlation analysis. This shared variance could explain the minimum contribution of barrier self-efficacy to the step count prediction model when task self-efficacy was included in the model. Additionally, the findings of this study also suggested that pre-pregnancy BMI seemed to play a role in predicting maternal PA participation at late third trimester (V4), but not at the end of the second trimester (V3). When pre-pregnancy BMI was entered into the model, it explained an additional 12.5% of variance in predicting step count at V4.

Little information is available about the relationship between exercise (i.e. walking) self-efficacy and PA participation among pregnant women. Therefore, there are many strengths of the present study that are unique contributions to the existing body of research in this area. First, the PA assessment tool used in this study was an objective measurement. Since walking is the most common activity among pregnant women, the objective measurement tool used in this study was the StepWatch™ Activity Monitor, an ankle-bound pedometer with previously reported high levels of accuracy and precision for measuring walking in various populations [50–52]. Self-reported PA of participants were not used in this study, which other researchers have suggested may be biased or result in under/over
reporting of actual PA [53–55]. Secondly, even though the present study has a small sample size of 37 women, it was a longitudinal study across pregnancy instead of a cross-sectional study at one time point during pregnancy. The same group of women was followed from the beginning of their second trimester until their late third trimester of gestation. Thirdly, the present study was the first to include pre-pregnancy BMI into a multiple regression model to predict maternal PA participation. Indeed, it showed that pre-pregnancy BMI added significant variance to the prediction model especially at the late third trimester. Lastly, this study also was the first to evaluate the exercise self-efficacy of overweight and obese pregnant women. In addition to dealing with excessive pre-pregnancy weight and potentially excessive gestational weight gain, overweight and obese women might also face many psychosocial factors which can prevent them from being physically active during pregnancy. For example, they may lack motivation and social support, not to mention self-efficacy. The psychosocial factors faced by overweight and obese women might be different from the normal weight women. The predictive strength of the statistical model might be different between the two groups as well; therefore, future studies might be needed to compare the walking self-efficacy between normal weight and overweight/obese women.

Despite the several strengths, it is acknowledged that the present study has some limitations. This intervention did not involve experimental manipulation of self-efficacy, therefore, the cause-effect relationship of exercise self-efficacy with PA participation that was observed in this study can only be assumed. Lastly, the population in this study was not diverse with respect to race, ethnicity or social economic status (SES); therefore, the findings of this study might not apply to a more diverse and lower SES population. The barriers faced by more diverse groups of pregnant women may be different.
Conclusion

In conclusion, self-efficacy and pre-pregnancy BMI are important in predicting PA participation during pregnancy especially at late pregnancy. When considering the health of the mother and fetus, particularly among the overweight and obese population, interventions designed to help increase PA participation during pregnancy are crucial. Psychosocial factors like self-efficacy are modifiable in a way that most demographic factors are not. Interventions designed to promote PA could focus on behavioral strategies for increasing self-efficacy toward PA participation during pregnancy, which then could bring positive influence to the health of the women and their children. The findings of the present study provided preliminary results in understanding the relationship between self-efficacy and PA participation during pregnancy, yet larger intervention studies are needed before a causal relationship can be established.

References


46. Gyurcsik NC, Bray SR, Brittain DR: **Coping with barriers to vigorous physical activity during transition to university.** *Fam Community Health* 2004, **27**:130–142.


Table 1: Correlations between pre-pregnancy BMI, barrier self-efficacy and task self-efficacy

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V3 (weeks 27-29 of gestation)

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V4 (weeks 34-36 of gestation)

* indicates $p < 0.0001$
Table 2: Linear regression and all-subsets analysis in predicting step count

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<th>Overall regression model (( p )-value)</th>
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TSE = task self-efficacy; BSE = barrier self-efficacy; Pre-BMI = pre-pregnancy BMI
Top 3 best models based on AIC values listed
RMSE = root-mean-square-error
Akaike information criterion
Figure 1: Barrier self-efficacy between treatment groups at end of second trimester (V3) and late third trimester (V4).

Overweight and obese pregnant women were enrolled and randomized to either intervention (encouraged to increase moderate intensity physical activity each week by walking) or control (no PA recommendations provided, but not restricted to PA participation) groups between weeks 15 – 35 of gestation. Barrier self-efficacy was assessed at V3 = weeks 27 – 29 of gestation, end of second trimester, and V4 = weeks 34 – 36 of gestation, late third trimester. At V3, there was a strong trend of significant difference between the treatment group (Int = 70.3%; Con = 57.0%; diff = 13.3%; p = 0.077); at V4, there was a significant difference between the treatment groups (Int = 64.6%; Con = 49.4%; diff = 15.2%; p = 0.045).

Figure 2: Task self-efficacy between treatment groups at end of second trimester (V3) and late third trimester (V4).

Overweight and obese pregnant women were enrolled and randomized to either intervention (encouraged to increase moderate intensity physical activity each week by walking) or control (no PA recommendations provided, but not restricted to PA participation) groups between weeks 15 – 35 of gestation. Task self-efficacy was assessed at V3 = weeks 27 – 29 of gestation, end of second trimester, and V4 = weeks 34 – 36 of gestation, late third trimester. At V3, there was a significant difference between the treatment group (Int = 78.2%; Con = 47.3%; diff = 30.9%; p < 0.0001); at V4, there was a significant difference between the treatment groups (Int = 73.7%; Con = 44.2%; diff = 29.5%; p < 0.0001).
Figure 1: Barrier self-efficacy between treatment groups at end of second trimester (V3) and late third trimester (V4).
Figure 2: Task self-efficacy between treatment groups at end of second trimester (V3) and late third trimester (V4).
CHAPTER 5: IMPACT OF A WALKING INTERVENTION DURING PREGNANCY ON POST-PARTUM WEIGHT RETENTION AND INFANT OUTCOMES

A paper to be submitted to journal Obesity

*Kai Ling Kong, Christina G Campbell, Kelly A Wagner, Anna D Peterson, Lorraine M Lanningham-Foster*

Abstract

Few studies have investigated the impact of physical activity interventions during pregnancy on post-partum weight retention and post-natal growth. **Objectives:** There were two objectives of the current study; 1) to compare maternal weight retention and child outcomes of overweight and obese participants enrolled in a walking intervention during pregnancy versus a non-intervention control group, and 2) to examine the relationship between pre-pregnancy body mass index (BMI) and rates of gestational weight gain (GWG) at different time points during pregnancy with maternal weight retention and infants’ weight-for-length z-scores (WLZ-scores). **Design and Methods:** Thirty seven overweight or obese (BMI ≥ 25.0 kg/m²) pregnant women were randomly assigned to a walking intervention or no-intervention control group. The length of the walking intervention was at least 20 weeks. Weight of the mother and weight, length and body composition of the infant were collected at one month post-partum (n = 37) and six months post-partum (n = 33). ANOVA was used to determine the differences in maternal post-partum weight and child outcomes. A Pearson correlation coefficient analysis was conducted to examine the association between pre-pregnancy BMI, rates of GWG at different time points across pregnancy, % weight retention and infant WLZ-score. **Results:** At six months post-partum, obese women in the
intervention group retained less than 1% of their maternal weight compared to obese women in the control group who retained 7% of their maternal weight. Lower WLZ scores at one month (Int-OB = -0.037 ± 0.615; Con-OB = 0.311 ± 0.520) and six months (Int-OB = 0.167 ± 0.706; Con-OB = 1.102 ± 1.332) were observed among infants who were born to obese women in the intervention group. Percentage of weight retention and WLZ score were significantly correlated with rates of GWG especially at the early time points during pregnancy. **Conclusion:** Targeting PA interventions for women early during pregnancy, or even before conception, could be a promising starting point for obesity prevention.

**Introduction**

The incidence of obesity among children has rapidly increased worldwide. Within the United States, 9.7% of infants and toddlers have a high weight-for-recumbent length and 16.9% of children and adolescents 2 – 19 years of age were obese (1). These values are concerning, as obese children and adolescents are more likely to become obese adults and possess obesity-associated morbidities later in life (2). The development of obesity has largely been attributed to unhealthy lifestyle choices or uncontrollable genetic predispositions; however, emerging evidence reveals that one’s exposure within the intrauterine environment may play a pivotal role in the development of obesity (3–5). The Developmental Origins of Health and Disease (DOHaD) hypothesis or better known as “Barker’s hypothesis” has been recently used to gain new insights into the obesity epidemic (4, 6, 7). The DOHaD hypothesis elucidates how an unfavorable intrauterine environment due to several conditions, including maternal obesity and excessive gestational weight gain (GWG), increases the risk of obesity in the offspring.

Maternal obesity and excessive GWG are two of the main causes of giving birth to a
large-for-gestational-age (LGA) (birth weight ≥ 90th percentile) infant in most Western countries (6–9). Further, evidence suggests that the association between maternal obesity and offspring obesity can be continued through childhood, adolescence, and into adulthood (10–13). When examining the relationship between excessive GWG and offspring obesity, epidemiological and observational studies have supported an association between the two (6, 8, 14). This is especially true among overweight and obese women compared to normal weight women (15–17). The latest data showed that in the U.S., 63% of overweight and 65% of obese women exceeded the IOM (2009) GWG recommendations (18). Unfortunately, the majority of these women also fail to lose weight after pregnancy, and excessive GWG is strongly associated with maternal weight retention at six and 12 months post-partum (8, 19, 20). Overweight and obese women retain more weight compared with women who are of normal weight prior to pregnancy (21). Overweight and obese women then carry this excess weight from one pregnancy to the next, and each subsequent pregnancy may result in more weight gain (19). This is concerning for the health of these women, as retention of gestational weight can be a significant contributor to long-term obesity and its associated health risks (22).

Besides the total amount of weight gained during pregnancy, the timing of GWG is also important (23). Weight gain at the beginning of pregnancy closely reflects maternal fat gain, while weight gain later in pregnancy reflects fetal components (23, 24). Thus, when a woman gains excessive weight early in pregnancy, her offspring may potentially be at risk for obesity (25, 26). Women increase their fat stores during early- and mid-pregnancy as a caloric reserve for feto-placental and increased maternal demands during late gestation and lactation (28); therefore, women entering into pregnancy who are overweight or obese are
not required to have an extra caloric reserve (27). In fact, women who are overweight or obese prior to conceiving should avoid excessive GWG at all costs. The current 2009 GWG recommendations by the Institute of Medicine (IOM) was developed based on a woman’s pre-pregnancy BMI (28). In general, obese women are advised to gain less weight than non-obese women.

Observational studies have supported the role of physical activity (PA) as a strategy for pregnant women to minimize, if not prevent, excessive GWG (29–32). Thus, many interventions have been designed to help women increase their PA participation during pregnancy to improve maternal and fetal health outcomes (33–38). Yet, few studies have investigated the impact of these interventions on maternal post-partum weight. Additionally, many of these interventions did not include follow-up studies to examine post-natal growth in the offspring of women who engaged in maternal PA during pregnancy. Therefore, the purposes of this study were 1) to compare maternal weight retention of participants enrolled in a walking intervention during pregnancy versus a non-intervention control group, as well as their child outcomes (weight-for-length z-score, fat mass and % fat mass) at one and six months post-partum; 2) to examine the relationship between pre-pregnancy BMI and rates of GWG at different time points during pregnancy with maternal weight retention and weight-for-length z-scores of infants at one and six months post-partum. Our hypotheses were 1) women who participated in the walking intervention during pregnancy would have less maternal weight retention and more favorable child outcomes compared to women who did not participate in the walking intervention during pregnancy; 2) pre-pregnancy BMI together with GWG in early pregnancy (< 20 weeks of gestation) would be significantly correlated to maternal weight retention and weight-for-length z-
scores of the infants in this study.

**Methods and Procedures**

**Study Design**

The Blossom Project team at Iowa State University conducted a pilot randomized controlled trial entitled ‘Moms to Move’ (M2M). The objectives of the M2M study were 1) to increase PA participation among previously non-exercising, overweight and obese pregnant women in order to meet the PA recommendations of 150 total minutes of moderate-intensity PA (MPA) spread throughout the week, via walking; 2) and to evaluate the impact of walking during pregnancy on GWG and birth outcomes when women meet the PA guidelines. The intervention in this study was a walking program. Women in the intervention group were advised to walk for at least 150 minutes per week. The women could spread the walk throughout the week, such as walking for 30 minutes, five days per week (39). Participants were allowed to walk in shorter bouts, however, women were advised to keep bouts at least 10 minutes in length (40). The walking program began no earlier than week 12 and no later than week 15 of gestation and lasted until at least week 35. Depending on the length of each participant’s pregnancy, all intervention participants were able to complete at least 20 weeks of the walking program. Walking could occur indoors, such as walking inside a mall, or outdoors, such as walking in the park. To help participants in the intervention group achieve the walking goal, treadmills were provided in women’s homes for the duration of the study and were returned following the completion of the program. Women in the control group were not provided recommendations with respect to PA participation, but they were not restricted from participating in any form of PA during pregnancy. The control group was not given treadmills for home use. Post-partum data
regarding the anthropometric information of mothers and infants were collected one and six months after delivery.

**Participants**

Recruitment for participants occurred from January 2011 to March 2012 through email, online advertisement, and flier postings throughout the community and in local obstetric clinics. Potential participants who expressed interest were screened for qualification criteria via email. Each participant was provided with an informed consent and assent document for review. The study was approved by the Institutional Review Board of Iowa State University.

All pregnant women were recruited before they began their fifteenth week of gestation. Gestational age was calculated based on the self-reported date of the patients’ last normal menstrual cycle or based on the due date determined by their medical providers using the clinical ultrasound. Forty-six pregnant women enrolled in the study. The final number of women who completed the gestational data collection was 37 ($n = 18$ in intervention group; $n = 19$ in control group), one month post-partum data collection was 37 ($n = 18$ in intervention group; $n = 19$ in control group), and six months post-partum collection was 33 ($n = 15$ in intervention group; $n = 19$ in control group). Details on dropouts were presented in Figure 1. Participants who were enrolled met the following inclusion criteria: maternal age between 18-45 years old, singleton pregnancy, non-smoker, self-reported overweight ($\text{BMI} \geq 25.0 \text{ kg/m}^2$) or obese ($\text{BMI} \geq 30.0 \text{ kg/m}^2$) prior to pregnancy, no prior history of chronic diseases (including type 1 diabetes, cardiovascular disease, thyroid disorder or lung disorder), and no prior history of gestational diabetes. Additionally, women were only recruited into the study if they engaged in leisure time
physical activity (LTPA) for 30 minutes or less fewer than three times per week during the 6 months prior to enrollment. Pre-pregnancy PA participation was self-reported and LTPA was defined as activities performed each week beyond normal daily routines.

**Procedure**

Participants who qualified through the email screening were invited for an enrollment appointment prior to week 15 of gestation. During the enrollment, participants signed the consent and assent forms, filled out the medical history questionnaire, and provided their medical providers’ contact information. Height and weight of the women were measured by a trained staff member after the consent form was signed. All participants were approved by their medical providers to join the study. After the initial enrollment, participants were randomly assigned to the intervention or control group. Randomization was conducted using Microsoft Excel randomization function (Microsoft Excel 2010, WA). All participants reported to the clinical research center at each of the following gestational data collection time points: weeks 10 – 14 (V1), 17 – 19 (V2), 27 – 29 (V3) and 34 – 36 (V4) of gestation, and post-partum time points: one month post-partum and six months post-partum. At each gestational data collection time point, anthropometric, objective physical activity, and self-reported diet data were collected for one-week at a time. Weeks 10 – 14 of gestation (V1) served as the baseline gestational data collection period. Participants in the intervention group had an additional intervention training session after the baseline visit. At each post-partum data collection time point, weight of the mother and weight, length and body composition of the infant were collected.

**Data Collection**

**Maternal anthropometric and demographic data**
Height and weight were measured at each gestational and post-partum data collection time point visit. Heights were measured to the nearest 0.1 cm with shoes removed (Ayrton 226 Hite-Rite Precision Mechanical Stadiometer, Quick Medical GS, Snoqualmie, WA) and weights were measured to the nearest 0.1 kg in light clothing (Detecto Model 6855 Cardinal Scale, Manufacturing Co., Webb City, MO). Pre-pregnancy BMIs were determined by using height measured at enrollment and women’s self-reported weights prior to conception. Weight retention was calculated by subtracting post-partum weight from self-reported pre-pregnancy weight. Weight retention was then converted to a percentage of weight retention (% wt. ret) based on each woman’s self-reported pre-pregnancy BMI. Individual weight change from 1 month to 6 months post-partum was further calculated and analyzed. Rate of GWG was determined by dividing the weight difference between two time points with the total weeks between the time points. Four different rates of GWG were calculated for the study: weight gain per week from 0 week to baseline data collection at V1 (considered as rate of weight gain before the start of the intervention, before M2M), weight gain per week between V1 and V2 (rate V1-V2), weight gain per week between V2 and V3 (rate V2-V3), and weight gain per week between V3 and V4 (rate V3-V4). During enrollment, participants reported their age, education level, employment, race, marital status, income level, and parity.

**Infant anthropometric data**

At the clinical research facility, infant lengths at one and six months were measured to the nearest 0.1 cm using a measuring board (seca 416, Medical Scales and Measuring Systems seca corp., Chino, CA). Body weights and body compositions were measured to the nearest 0.001 kg (PEA POD® or BOD POD Pediatric Option™, COSMED USA, Concord,
CA). PEA POD® and BOD POD Pediatric Option™ are systems for body composition measurement based on air displacement plethysmography. Instruments were calibrated once daily during testing days. The weight limit of the PEA POD® is 12,000 kg; therefore two six months babies were measured using the BOD POD Pediatric Option™. Before the measurement of weights and body composition, infants were undressed and baby oil was used to smooth the infants’ hair down to eliminate air trapped in her/his hair. Body weights and body compositions needed to be performed on babies with clothing removed in the PEA POD®; however, light-weighted and form-fitting shorts were provided for infants measured using the BOD POD Pediatric Option™. Infants were weighed first and then body volume was assessed while infants were lying in the chamber of PEA POD or sitting on the inserted chair of BOD POD while he/she was awake.

To maintain consistency, account for sex differences, and enable comparison of effect sizes, all infant anthropometric outcomes were converted to z-scores. Infant weights (WAZ), lengths (LAZ), and weight-for-lengths (WLZ) at one and six months were calculated to sex- and age-specific z-scores using the 2000 Centers for Disease Control/National Center for Health Statistics growth charts (41).

**Statistical analysis**

Demographic data were analyzed by descriptive analysis. Multivariate analysis of variance was conducted to examine differences in demographic variables (age, height, pre-pregnancy weight, pre-pregnancy BMI, education, employment, race, marital status, total household income, parity) between the groups. Two-way analysis of variance (ANOVA) was used to determine the differences in weight retention (kg), % wt. ret, and child outcomes (weight, length, WAZ score, LAZ score, WLZ score, fat mass and % fat mass) by
treatment group and pre-pregnancy BMI (pre-BMI) category. Absolute difference (diff) was reported to show the magnitude and direction when there was significant difference. Pairwise comparison tests (all pairs Tukey-Kramer \( p = 0.05 \)) were then performed to further determine the differences among overweight women in the intervention group (Int-OW), overweight women in the control group (Con-OW), obese women in the intervention group (Int-OB), and obese women in the control group (Con-OB) on the above mentioned variables. A Pearson correlation coefficient analysis was also conducted to examine the association between pre-pregnancy BMI, rates of GWG at different time points across pregnancy, \% wt. ret and WLZ score at one and six months post-partum. Significance was defined as \( P < 0.05 \). Results are presented as mean ± standard deviation (mean ± SD). Data analyses were conducted using JMP, Version 7 (SAS Institute Inc., Cary, NC).

Results

Participant characteristics

Participant characteristics in each group by treatment and BMI category can be found in Table 1 of Chapter 3. There was no significant difference between groups for age, height, gestational length at V1, education, employment, race, marital status, total household income, and parity. Pre-pregnancy weight and pre-pregnancy BMI were significantly different between overweight and obese participants. Majority of the participants in this study were married, educated, and Caucasian.

Maternal post-partum weight

At 1 month post-partum, there was no significant difference between the treatment groups, pre-pregnancy BMI categories and interaction effect for both weight retention (\( F = 0.420; p = 0.7400 \)) and \% wt. ret. (\( F = 0.468; p = 0.7069 \)). For 6 months post-partum weight
retention, there was no significant difference between the treatment groups and pre-pregnancy BMI categories, but there was a significance in the interaction effect \( p = 0.0438 \) \( (F = 2.488; \ p = 0.0795) \); while, for 6 months post-partum % wt. ret., there was no significant difference between the treatment groups and pre-pregnancy BMI categories, but a strong trend of significance in the interaction effect \( p = 0.0588 \) \( (F = 2.143; \ p = 0.1157) \). The pairwise comparison tests did not show significant differences between the four participant groups (Int-OW, Con-OW, Int-OB, and Con-OB) at each post-partum time point (Table 1). However, at one month post-partum, % wt. ret of Int-OB women was 2.0% and this value decreased to 0.8% at six months post-partum. In contrast, at one month post-partum, % wt. ret of Con-OB was 3.4% and this value increased to 7.0% at six months post-partum.

Individual weight changes from 1 month to 6 months post-partum were further analyzed and were classified as gain or loss (Figure 2). The percentage of women who gained or lost weight from 1 to 6 months post-partum was relatively similar among the overweight women between the treatment groups; however, there were a higher percentage of obese women in the control group who gained weight from 1 to 6 months post-partum compared to the obese women in the intervention group.

**Child outcomes**

Overall, there were no significant differences in weight \( (F = 0.425, \ p = 0.736 \text{ at 1 month}; \ F = 0.364, \ p = 0.780 \text{ at 6 months}) \), length \( (F = 0.148, \ p = 0.930 \text{ at 1 month}; \ F = 0.040, \ p = 0.989 \text{ at 6 months}) \), WAZ score \( (F = 0.434, \ p = 0.730 \text{ at 1 month}; \ F = 0.801, \ p = 0.504 \text{ at 6 months}) \), LAZ score \( (F = 0.087, \ p = 0.966 \text{ at 1 month}; \ F = 0.024, \ p = 0.995 \text{ at 6 months}) \), WLZ score \( (F = 0.456, \ p = 0.715 \text{ at 1 month}; \ F = 1.403, \ p = 0.262 \text{ at 6 months}) \), fat mass \( (F = 0.274, \ p = 0.844 \text{ at 1 month}; \ F = 0.867, \ p = 0.470 \text{ at 6 months}) \), and % fat mass (F
= 0.395, \( p = 0.758 \) at 1 month; \( F = 0.911, \ p = 0.448 \) at 6 months) between the treatment groups, pre-pregnancy BMI category, or interaction effect at each post-partum visit. Lower WLZ scores at one month (Int-OB = -0.037; Con-OB = 0.311; diff = 0.348; \( p = 0.7904 \)) and six months (Int-OB = 0.167; Con-OB = 1.04; diff = 0.873; \( p = 0.430 \)) were observed among infants who were born to obese women in the intervention group compared to babies born to obese women in the control group. However, pairwise comparison tests showed no significant difference.

**Pre-pregnancy BMI and rates of gestational weight gain at different time points on maternal and child weight**

Table 3 is a correlation matrix, which demonstrates the association between pre-pregnancy BMI and rates of GWG at different time points during pregnancy, with \% weight ret of the women and WLZ score of the child at one month and six months post-partum. Rate of GWG was calculated for weight gained before women joined the study (before M2M), rate of GWG between V1 and V2 (rate V1-V2), rate of GWG between V2 and V3 (rate V2-V3), and rate of GWG between V3 and V4 (rate V3-V4). Table 3 shows that the rates of GWG at different time points were significantly correlated with the preceding rate of GWG. Rate of GWG between V1 and V2 (rate V1-V2) was significantly correlated with the rate of weight gain before the women joined the study (before M2M) \( (r = 0.493, \ p < 0.01) \); rate V2-V3 was significantly correlated by V1-V2 \( (0.457, \ p < 0.01) \); rate V3-V4 was significantly correlated with V2-V3 \( (0.469, \ p < 0.01) \). Percentage of weight retention at one month and six months post-partum was significantly correlated with all rates of GWG at different time points throughout pregnancy, but not pre-pregnancy BMI. Weight-for-length z-score at one month post-partum was not significantly correlated with any rate of GWG or
pre-pregnancy BMI. However, WLZ score at six months post-partum was significantly correlated with rate of GWG before M2M, rate V1-V2, and rate V3-V4.

Discussion

The current study examines the impact of a walking intervention during pregnancy on women’s weight retention at one and six months post-partum and the impact on infant outcomes. At six months post-partum, obese women in the intervention group retained less than 1% of their maternal weight compared to 7% weight retention among obese women in the control group. Obese women in the control group experienced a 3.54% weight gain from one month to six months post-delivery. In contrast, obese women in the intervention group reduced their weight by 1.22% from one month to six months post-delivery. When individual weight change was further analyzed, a higher percentage of the obese women in the control group gained weight from one month to six months post-partum compared to obese women in the intervention group. In other words, a higher percentage of the obese women who participated in the walking intervention continued to lose the weight they had gained during pregnancy. Evidence shows that prenatal PA has the capability to help pregnant women minimize, if not prevent, excessive GWG (29–32); however, less is known about the effect of prenatal PA on gestational weight retention during the post-partum period. The walking intervention within this study was successful in changing the walking patterns (behavior) of the overweight and obese women in the intervention group (reported elsewhere). These women walked at a higher intensity and were, most importantly, able to sustain these walking habits until late pregnancy. As a result, the reduced weight retention among obese women in the intervention group may be explained in part by the lifestyle modification during pregnancy. During the post-partum period, obese women in the
intervention group may have continued their higher intensity walk, even after intervention termination.

Thus far, no known study has evaluated the impact of lifestyle intervention, using increased PA as the only modification during pregnancy, on post-partum weight retention. However, presently, two studies have examined the effects of PA together with dietary modification during pregnancy on post-partum weight retention (38, 42). Both studies showed that a significantly higher percentage of women in the physical activity/diet intervention group returned to their pre-conception weight when compared to the control group at 6 months post-partum.

The current study did not observe differences in regards to the child’s body fat mass or % body fat between the groups (Int-OW, Con-OW, Int-OB and Con-OB). Although not statistically significant, there was a tendency for the offspring of obese women in the intervention group to have lower WLZ scores at one and six months old. In fact, this strong trend starts at birth; as obese women who participated in the walking intervention had lower infant birth weight z-scores and decreased odds of fetal macrosomia (data reported elsewhere). Overall, this is an encouraging finding within the present study. Evidence shows that maternal PA participation helps reduce the risk of giving birth to LGA infants (43–45). Unfortunately, to date, there is limited research that examines long-term longitudinal data on post-natal growth in the offspring of women who engaged in maternal PA during pregnancy. There are currently three such studies in the literature, yet these findings are based on observational studies rather than intervention follow-up studies (46–48). Different from our study population, two studies by Clapp and colleagues recruited women who were recreational athletes (i.e.: runners, cross-country skiers) and found conflicting results. In one
study, offspring of the women who continued their exercise regimens during pregnancy weighed less and were leaner at age 5 when compared to the control group’s offspring (previously recreational athletes who stopped all sustained exercise) (47). Interestingly, in the second study, Clapp and colleagues did not observe the same effect when measurements were taken at age 1 (46). In a more recent women/toddler pairs study (n = 23), Mattran and colleagues found that recall of LTPA at 3rd trimester (MET-min/wk) was marginally associated with lower toddler weight ($r_s = -0.39$, $p = 0.06$) and weight-for-height z-score ($r_s = -0.40$; $p = 0.06$) between 18 to 24 months of age in the offspring (48).

The present study also suggests a “cascade effect” of weight gain throughout pregnancy. Rate of GWG at any point during pregnancy was significantly associated with the preceding rate of weight gain. In this study, weight gain after enrollment into the walking intervention was affected strongly by the weight already gained before the start of the intervention. This observed effect could be especially discouraging to investigators who hope to introduce lifestyle modifications during pregnancy to prevent excessive GWG. One such example is the NELIP study conducted by Mottola and colleagues, a personalized walking program that began between 16 and 20 weeks of gestation (37). The results of this intervention showed that 80% of the participants did not exceed 2009 IOM recommendations on NELIP and their average total weight gain on NELIP was only $6.8 \pm 4.1$ kg. Unfortunately, many women had gained excessive weight before they joined the program; therefore, their average total weight gain was $12.0 \pm 5.7$ kg, which exceeded the total GWG range recommended by IOM for both overweight and obese women. Consequently, the suggestion by Weisman et al. to target the pre-conception period in order
to help women reduce overall weight and increase PA participation before entering pregnancy might be an effective strategy worth future investigation (18).

In addition to the observed “cascade effect” of GWG, all rates of GWG across the gestational period were significantly associated with the percentage of weight retention at one and six months post-partum. It is well documented that total GWG is positively associated with post-partum weight retention (8, 19, 20) and is a strong predictor of long-term overweight and obesity beyond pregnancy (49, 50). However, little information is available about the patterns of weight gain across the gestational period in relation with post-partum weight retention. Muscati and colleagues argued that timing of GWG was as important as the total amount of weight gain during pregnancy (23). They provided evidence that early GWG (≤ 20 weeks) was a strong predictor of six weeks post-partum weight retention. They further concluded that rate of weight gain during the first half of pregnancy should be carefully monitored among overweight women in order to avoid excessive fat deposition. The results of the present study did not concur with the findings of Muscati and colleagues. The present study shows that GWG during the second half of pregnancy (≥ 20 weeks) could also play a significant role in predicting weight retention at one and six months post-partum. Nevertheless, more studies are needed to better understand the relationship between the timing of GWG and post-partum weight retention.

When evaluating the relationship between GWG and child WLZ score, the current study did not demonstrate a relationship between pre-pregnancy BMI and rates of GWG at any point during pregnancy with one month infant WLZ score. However, a relationship was identified at six months WLZ score, especially in early pregnancy weight gain (≤ 20 weeks of gestation). Similarly with post-partum weight retention, the relationship between GWG
and offspring obesity is well established (6, 8, 14), yet very few studies have investigated the pattern of weight gain across the gestational period in relation to offspring obesity. The finding of the present study is supported by one other study, which evaluated GWG during two specific periods: 0 to 14 weeks and 14 to 36 weeks. Using the Avon Longitudinal Study of Parents and Children (ALSPAC), a UK-based prospective pregnancy cohort (n = ~12,500), Fraser and colleagues reported a positive relationship between GWG in early pregnancy (0 to 14 weeks) and offspring adiposity at age 9 years in all data, while GWG was only related with offspring adiposity in women who gained > 500 g/wk between 14 and 36 weeks (25). Through these findings, the authors concluded that women should avoid excessive weight gain in early pregnancy, as this early weight gain may cause the relationship between GWG and offspring adiposity.

Evidence of the impact of maternal PA participation on post-partum weight retention and child obesity among overweight and obese women is limited. Therefore, there are many strengths of the present study, which provided unique contributions to the existing body of research in this area. The PA assessment tool used during the pregnancy portion of the study was an objective measurement. As a result, the study did not rely on women to self-report or recall their PA participation during pregnancy, eliminating any potential bias or under/over reporting of actual PA participation (51–53). Even though the present study has a small sample size of 37 women, it longitudinally studied women across pregnancy rather than taking a cross-sectional sample at one time point. Among the 37 participants, all women were followed until one months post-partum, and 33 women were followed until six months post-partum. This study is the first to evaluate the impact of an independent PA intervention on the postnatal growth in offspring of overweight and obese pregnant women using a
randomized controlled trial. The positive findings of the present study could serve as preliminary data for future investigations in a larger randomized controlled trial. Lastly, this study was able to track the rate of weight gain at different time points during pregnancy by trained staff members. This is advantageous as the information collected could provide a better understanding of how the timing and the pattern of GWG affect post-partum weight retention and postnatal child growth.

It is acknowledged that the present study has several limitations that should be noted. One major limitation of the current study is its small sample size and high variability among the groups. The small sample size could have reduced the ability to detect statistically significant effects of the intervention on post-partum maternal and child outcomes. Secondly, self-reported pre-pregnancy BMI was used in the study, which could lead to an inaccurate percentage of weight retention calculation because evidence has shown that overweight women are more likely to underreport their weight compared to normal or underweight women (54). Thirdly, the present study did not collect any PA or dietary data during the post-partum period. Therefore, the effects observed between PA participation during pregnancy and post-partum maternal and child outcomes can only be assumed. Lastly, this study did not account for other confounding factors, such as feeding practices and sociodemographic variables when association of rates of GWG with maternal and child outcomes during post-partum period were reported. Evidence has shown that breastfeeding, maternal age, race, and employment status are associated with weight retention (55, 56).

In conclusion, it was surprising and unexpected that there was not a similar relationship between changes in PA pattern/intensity and post-partum weight retention and child health outcomes for both overweight and obese participants. It would appear that
lifestyle modification during pregnancy provided greater benefit for the obese women and possibly their offspring. In this study, even though the walking intervention during pregnancy did not significantly increase the minutes of meaningful walks taken by the obese women, it was successful in changing the intensity/pattern of their walks, and they were able to sustain those habits until late pregnancy. It is stated in the 2008 Physical Activity Guidelines for Americans that some activity is better than none (57); therefore, small change for previously non-exercising, obese pregnant appeared to bring health-related benefits. Maternal obesity and excessive GWG cause a perpetuating “vicious cycle” of obesity, where obese women or women who gain excess gestational weight have a higher risk of giving birth to large for gestational age infants, who then, years later, can become obese adults entering into their own pregnancies (58) These women are also more likely to retain gestational weight, which then leads to higher weight status for future pregnancies (19). Therefore, targeting PA interventions for women during early pregnancy, or even before conception, could be a promising starting point for obesity prevention.

References


### Table 1: Post-partum maternal weight by treatment and pre-pregnancy BMI

<table>
<thead>
<tr>
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<th>Overweight</th>
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<td>Intervention (n = 8)</td>
<td>Control (n = 10)</td>
<td>Intervention (n = 7)</td>
<td>Control (n = 9)</td>
</tr>
<tr>
<td>Maternal weight</td>
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<td></td>
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<td></td>
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<tr>
<td>Weight retention (kg)</td>
<td>5.34 ± 6.05</td>
<td>1.62 ± 5.58</td>
<td>1.43 ± 5.36</td>
<td>3.05 ± 8.24</td>
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<td>% weight retention (%)</td>
<td>7.73 ± 8.73</td>
<td>2.46 ± 7.31</td>
<td>2.02 ± 5.90</td>
<td>3.43 ± 9.25</td>
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<td>6-month post-partum</td>
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<td></td>
<td></td>
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<tr>
<td>Weight retention (kg)</td>
<td>1.64 ± 2.09</td>
<td>-0.94 ± 5.60</td>
<td>-0.10 ± 8.11</td>
<td>6.35 ± 7.47</td>
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<tr>
<td>% weight retention (%)</td>
<td>2.44 ± 2.97</td>
<td>-0.79 ± 6.98</td>
<td>0.80 ± 7.85</td>
<td>6.97 ± 8.34</td>
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Values shown are mean ± SD

% weight retention was calculated using self-reported pre-pregnancy weight
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<th>Variables</th>
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<th>6-month post-partum</th>
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<tr>
<td>Child outcomes</td>
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<td>Weight (kg)</td>
<td>4.49 ± 0.48</td>
<td>4.63 ± 0.59</td>
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<tr>
<td>Length (cm)</td>
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<td>-0.37 ± 0.76</td>
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<td>WLZ score</td>
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<td>Fat mass (kg)</td>
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<td>Fat mass (%)</td>
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<td>Child outcomes</td>
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<tr>
<td>Weight (kg)</td>
<td>7.94 ± 0.98</td>
<td>7.94 ± 1.21</td>
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<td>Fat mass (%)</td>
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Values shown are mean ± SD

WAZ score = weight-for-age z-score; LAZ score = length-for-age z-score; WLZ = weight-for-length z-score
Table 3: Correlations between pre-pregnancy BMI and rates of gestational weight gain with % weight retention and child WLZ scores

<table>
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<th>Before M2M</th>
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<th>Rate V2-V3</th>
<th>Rate V3-V4</th>
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<th>6-m % wt. ret</th>
<th>1-m WLZ</th>
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<tr>
<td>Before M2M</td>
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<td>0.49**</td>
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<td>Rate V2-V3</td>
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<td>0.46**</td>
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<tr>
<td>Rate V3-V4</td>
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<td>0.36*</td>
<td>0.47**</td>
<td>1</td>
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<tr>
<td>1-m % wt. ret</td>
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<td>0.52**</td>
<td>0.75***</td>
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<td>6-m % wt. ret</td>
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<td>0.60***</td>
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* indicates $p < 0.05$; ** indicates $p < 0.01$; *** indicates $p < 0.001$
V1 = weeks 10-14 of gestation; V2 = weeks 17-19 of gestation; V3 = weeks 27-29 of gestation; V4 = weeks 34-36 of gestation; % wt. ret = % weight retention; M2M = Moms to Move study; WLZ = weight-for-length z-score
Overweight and obese pregnant women were enrolled and randomized to either a walking intervention or control group during pregnancy. Maternal weight was collected at 1 month and 6 months post-partum. Individual weight change was classified as gain or loss from 1 month post-partum to 6 months post-partum. (Int-OW = overweight women in the intervention group; Con-OW = overweight women in the control group; Int-OB = obese women in the intervention group; Con-OB = obese women in the control group)
Figure 1: Participant flow chart
Figure 2: Percentages of women who gained or lost weight from 1 month to 6 months post-partum
CHAPTER 6: GENERAL CONCLUSIONS

The intrauterine environment of obese women and of those with excessive gestational weight gain could potentially program long-term offspring obesity (Oken, 2009). In the words of Barker, ‘The womb may be more important than the home’ (Barker, 1990). In these past few decades, physical activity during pregnancy has been viewed as an important part of reproductive health. Pregnant women are encouraged to have an active lifestyle, which has replaced the traditional view that pregnant women should engage in limited exercise (Downs, Chasan-Taber, Evenson, Leiferman, & Yeo, 2012). According to the 2008 PA guidelines for Americans, in the absence of either medical or obstetric complications, pregnant women are encouraged to accumulate a total of 150 minutes of moderate PA per week, preferably spread throughout the week (“Physical activity guidelines advisory committee report, 2008. To the Secretary of Health and Human Services. Part A: executive summary,” 2009).

To our knowledge, the current intervention was the first pilot randomized controlled trial to help previously non-exercising, overweight and obese women to increase moderate PA during pregnancy via walking. It was a PA-only intervention. Diet counseling was not provided nor was caloric restriction emphasized in the study. Additionally, the present study also was the first to objectively measure walking cadence/intensity of pregnant women in order to evaluate moderate PA participation during pregnancy in a randomized-controlled trial. The results of the study (Chapter 3) showed that the walking intervention helped change the walking intensity of all women enrolled in the intervention group during pregnancy especially among the overweight women. Even though it was not statistically
significant, there was a trend for women in the intervention group to have more favorable pregnancy and birth outcomes compared to the control group.

Little information is available about the relationship between exercise (i.e. walking) self-efficacy and PA participation among pregnant women. The present study (Chapter 4) showed that self-efficacy and pre-pregnancy BMI are important in predicting PA participation during pregnancy especially at late pregnancy. Psychosocial factors like self-efficacy are modifiable in a way that most demographic factors are not (Hinton & Olson, 2001). Interventions designed to promote PA could focus on behavioral strategies for increasing self-efficacy toward PA participation during pregnancy, which then could bring positive influence to the health of the women and their children.

Furthermore, evidence shows that prenatal PA has the potential to help pregnant women minimize, if not prevent, excessive GWG (Haakstad, Voldner, Henriksen, & Bø, 2007; Olson & Strawderman, 2003; Stuebe, Oken, & Gillman, 2009); however, less is known about the effect of prenatal PA on gestational weight retention during the post-partum period. The follow-up study (Chapter 5) of the current walking intervention showed that at six months post-partum, obese women in the intervention group retained less weight than the obese women in the control group. The obese women in the intervention group continued to lose the weight they had gained during pregnancy from one-month to six-month post-partum. In contrast, obese women in the control group experienced weight gain from one month to six months post-delivery. In addition, thus far, there is limited research that examines long-term longitudinal data on post-natal growth in the offspring of women who engaged in maternal PA during pregnancy. Although not statistically significant, in the present study there was a trend for the offspring of obese women in the intervention group to
have lower WLZ scores at one and six months old. In fact, this trend started at birth; as obese women who participated in the walking intervention had lower infant birth weight z-scores and decreased odds of fetal macrosomia. Overall, it was surprising and unexpected that there was not a similar relationship between changes in PA pattern/intensity and post-partum weight retention and child health outcomes for both overweight and obese participants. It would appear that lifestyle modification during pregnancy benefited the obese women themselves and perhaps their children. In this study, the walking intervention during pregnancy was successful in changing the intensity/pattern of walking, and obese participants were able to sustain the walking until later in pregnancy. The 2008 Physical Activity Guidelines for Americans states that some physical activity is better than none (57). Perhaps for some populations like obese pregnant women, we may need to consider that the amount of walking is not as important as how the walking is performed.

In conclusion, maternal obesity and excessive GWG cause a perpetuating “vicious cycle” of obesity, where obese women or women who gain excess gestational weight have a higher risk of giving birth to large for gestational age infants, who then, years later, can become obese adults entering into their own pregnancies. These women are also more likely to retain gestational weight, which then leads to higher weight status for future pregnancies. Therefore, targeting PA interventions for overweight and obese women during pregnancy could be a promising starting point for obesity prevention. Figure 2 serves as a summary of the overall impact of the Moms To Move Study on the “vicious cycle” of obesity. The findings of the present study will serve as preliminary data for future investigations in a larger randomized-controlled trial.
Figure 2: Overall impact of the Moms To Move Study on the “vicious cycle” of obesity.

**References:**


APPENDIX A. RECRUITMENT MATERIALS

Copy of email to send to ISU faculty, staff and students:

Are you or is someone you know pregnant?
We are conducting a study to better understand how walking can benefit women during pregnancy.
QUALIFICATION CRITERIA INCLUDES:

- Less than 14 weeks pregnant
- At least 18 years of age
- Exercise less than 3 days a week
- Pregnant with only one baby
- Non-smoker
- No physical restrictions to walking 30 min at a time
- No history of gestational diabetes, chronic disease, lung or thyroid disorder
- No use of pacemaker or portable oxygen

A maximum of 6 study sessions are required. Eligible participants will be compensated. Participation is voluntary.

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

The Blossom Project is affiliated with Iowa State University.
Be part of

The Blossom Project

Improving the lives of women and their babies...
one pregnancy at a time

If you or is someone you know is PREGNANT, contact us.
We are currently recruiting for several studies.
Eligible participants will be compensated.
Participation is voluntary.

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

IOWA STATE UNIVERSITY
OF SCIENCE AND TECHNOLOGY
APPENDIX B. APPROVED CONSENT FORM

CONSENT FORM FOR: THE BLOSSOM PROJECT
Moms2Move (M2M)

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.

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 who has expressed interest in our study by responding to our recruiting efforts. You have been selected to participate based on several factors:

- less than 14 weeks pregnant;
- between 18 and 45 years of age;
- were overweight before becoming pregnant;
- not pregnant with multiple babies (e.g. twins);
- have not smoked since becoming pregnant;
- do not have a history of gestational diabetes, chronic disease, lung or thyroid disorders;
- did not exercise more than 3 times per week for 6 months prior to conception;
- do not have a pacemaker or electromagnetic device or use portable oxygen;
- are willing to walk 30 minutes on most days of the week throughout your pregnancy; and
- can communicate without language or mental status barriers.

What is the purpose of this study?
The objective of this study is to evaluate a walking program on risk associated with pregnancy complications in pregnant women. By lowering the risk of complications, we may ultimately improve the future health of both mother and child. The physical activity intervention consists of 30 minutes of walking time per day on most days of the week. A treadmill will be provided to you for your home-use, at no cost, to make it easier to complete the walking. The treadmill must be returned at the end of your pregnancy.

You will be randomly assigned to the walking program or control group. Women participating in the control group will be asked to participate in the same data collection process however they will not be provided a treadmill.

Throughout your pregnancy, at any time you are invited to discuss concerns that you have about the study protocol. If you are diagnosed with multiple fetuses, or miscarry after enrolling in the study, you will no longer be able to participate in the study.
What will I be asked to do?
If needed, a visual representation of the overall study is provided at the end of the consent form. If you agree to participate, you will be asked to do the following:

Data Collection Period 1 (~60 minutes):
During the visit, the consent form will be explained by a staff member. Prior to signing the consent form, you will have the opportunity to discuss the consent form approved by the Iowa State University Institutional Review Board (ISU-IRB) with a staff member. A hard copy of the consent form will be provided to you for your records. After consenting to participate, you will complete a medical history questionnaire. At this meeting you will also complete a questionnaire about the amount and type of physical activity that you have done since becoming pregnant. Lastly, we will obtain your height (no shoes or bulky clothes), and current weight (lightweight clothing, no shoes).

Following this meeting, a form will be sent to your medical provider. You will be asked to provide contact information for your medical provider and to sign this form; we will fax it to your medical provider. We will obtain approval from the medical provider regarding your participation as well as your weight at your first prenatal visit. You cannot begin the physical activity program until we receive agreement from your medical provider. If we do not receive approval by week 18 you will not be allowed to continue in the study.

Data Collection Period 2 (~60 minutes):
This visit will occur between week 10 and 14.

A member of the study team will schedule this visit. We will accommodate your schedule to the best of our ability; however the appointment needs to be within the weeks identified above.

You will report to the Nutrition and Wellness Research Center (NWRC) at the ISU Research Park or on-campus (2022 HNSB) in the morning having fasted overnight for at least 8 hours. During the fasting period you should not consume any food or beverages, however, water is acceptable. You are encouraged to drink water the night before and the morning of the blood draw to promote adequate hydration to facilitate the blood draw process.

We will take a current weight (lightweight clothing, no shoes), determine body composition using bioelectrical impedance (BIA), obtain a fasting blood sample from the upper extremity, typically in the front of the arm opposite the elbow, give instructions on the weighed 3-day diet record, and fill out a pregnancy physical activity questionnaire. Your percentage of body fat will be measured using bioelectrical impedance analysis (BIA). Four electrodes will be placed on you (foot, ankle, wrist, and finger) to measure the resistance to the current flow in your body. This is a very safe method and you will not feel anything throughout this process. The weighed 3-day diet record requires you to weigh and record all food and beverages consumed for two 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 will return the scale to use when you turn in your weighed 3-day diet record. 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.

For the next 7 days, your current activity level will be measured using the Sensewear Mini armband and Step Watch. The Sensewear Mini is a device that assesses the amount of calories you use during the day, is worn on the upper left arm, and looks like an iPod. The Stepwatch is a device worn around the ankle and determines the number of steps you take in a day; it is a research grade pedometer. During this visit, you will learn how to properly place both devices. You will be asked to wear these devices at all times except when showering or swimming. You will need to assure that you put them back on following any of these activities. One week after wearing the Sensewear and Step Watch, you will need to return the devices. You will arrange this meeting with a member of the study team.
Walking Program:
If you are assigned to the walking program this following information describes the expectations. The intervention will begin no earlier than week 12 and no later than week 15 and last until at least week 35. The first three weeks of the intervention will allow for a gradual increase in walking time. The goal of the intervention is to add 30 minutes of walking time above your usual walking time (determined during visit 2). The amount of walking will be increased by 10 minutes/day (week 1), 20 minutes/day (week 2) and 30 minutes/day (week 3). By week 18, you should be at your walking goal, which is 30 min of walking on most days of the week as recommended by American College of Obstetrics and Gynecologists for a total of at least 150 minutes per week. During these three weeks, one of our staff members will contact you weekly to answer study-related questions and address any concerns.

Walking can occur indoors (e.g. mall) or outdoors (e.g. park). To help you achieve your walking goal you will be provided a treadmill for your home. The treadmill will be delivered to your home via UPS or by members of the Blossom Project Research Team. It will be easy to set-up and light weight yet durable. You may need to find assistance to set-up the treadmill in your home. You will be provided with instructions on how to get on and off the treadmill and how to wear the accompanying safety device provided with the treadmill. To promote your own safety, you are encouraged to read and follow the manufacturer's guidelines.

Data Collection Periods 3, 4 and 5 (~60 minutes per visit):
These visits will occur between week 17-19, 27-29 and 34-36.

A member of the study team will schedule these visits. We will accommodate your schedule to the best of our abilities; however the appointment needs to be within the weeks identified above.

You will report to the Nutrition and Wellness Research Center (NWRC) at the ISU Research Park on-campus (2022 HNSB) in the morning having fasted overnight for at least 8 hours. During the fasting period you should not consume any food or beverages, however, water is acceptable. You are encouraged to drink water the night before and the morning of the blood draw to promote adequate hydration to facilitate the blood draw process.

We will obtain a current weight, determine body composition using BIA, obtain a fasting blood sample from the upper extremity, typically in the front of the arm opposite the elbow, and fill out pregnancy physical activity questionnaire.

For the next 7 days, your current activity level will be measured using the Sensewear Mini armband and Step Watch. One week after wearing the Sensewear and Step Watch, you will need to return the devices. You will arrange this meeting with a member of the study team.

At data collection periods 4 and 5, we will ask you if you have had any pregnancy-related complications since your previous appointment. In particular we will want to know the results of your oral glucose tolerance test performed by your medical provider. We will also like to know some of the barriers you might face that could stop you from walking by having you to fill out a barrier self-efficacy questionnaire. We will also like to know your confidence in being physically active by walking during these two data collection periods.

At data collection period 5, you will be provided with a list of information that we will want to know at the follow-up visit. This will include information regarding the type of delivery that you had, your baby's birth outcomes (sex, weight, length, head circumference, and APGAR scores), and your body weight at your last prenatal appointment. We will also ask you to fill out exercise regulations questionnaire and psychological need satisfaction in exercise scale to evaluate your motivation and psychological need fulfillment in walking.
**Data Collection Period 6 (60 minutes):**
One month after your delivery, you and your baby will attend a follow-up visit.

This visit will occur at the Nutrition and Wellness Research Center at the ISU Research Park. You, the mom, will need to be fasted for 8 hours for a blood draw in the morning. We will measure your weight after the blood draw. Then, you will complete a final survey; this includes reporting the type of delivery, complications during delivery, your weight at your last prenatal visit, and your baby's birth outcomes. We will weigh your baby in a pan-type pediatric electronic scale similar to the one used in your doctor's office. Your infant's body fat will be measured during this visit using a state-of-the art, safe, non-invasive method called a PEA POD. Your baby will be placed in a temperature-controlled test chamber with a continuous outside air source for a brief amount of time (less than one minute).

**Data Collection Period 7 and 8 (60 minutes):**
Six months and 1 year after your delivery, you and your baby will attend a follow-up visit at each time period.

This visit will occur at the Nutrition and Wellness Research Center at the ISU Research Park. We will measure your weight. For your baby, we will collect body weight (using a pan-type pediatric electronic scale), body length (using a stationary headboard/movable footboard device) and body composition (using the PEA POD).

We will collect information in regards to feeding practices (e.g. breastfeeding, formula feeding, introduction of solids) and developmental milestone achievement (e.g. rolling, sitting, crawling, walking). We will also like to know some of the barriers you might face that could stop you from walking during post-partum period by having you to fill out a barrier self-efficacy questionnaire. We will also like to know your confidence in being physically active by walking during post-partum period.

**Throughout the study:**
You (either in the walking program or the control group) will be provided with a walking calendar so you can record the amount of time and the days you spend walking each week. You will return the walking calendar each visit.

If you are in the walking program group, you will also be provided a pedometer (step-counter) to wear around your waist or ankle. The pedometer is a tool for you to use, if it helps you reach your walking goals; wearing this is optional.

**What are the possible risks and benefits of my participation?**
**Risks** — Potential risks of the study are minimal. The study does not provide any foreseeable risks to you and your fetus. Blood samples may be uncomfortable; blood will be drawn by an experienced phlebotomist under strict aseptic conditions to minimize pain and infection risk. You may also experience discomfort from fasting overnight for the blood draws. Immediately following the blood draw, if you feel faint or nauseous we have juice and crackers available. Some individuals experience skin irritation from wearing the Mini armband. If this happens to you, we will provide general recommendations about periodically moving the armband, and if necessary, removal of the armband during sleep. However, if this does not work, you will be allowed to stop wearing your armband; a 24-hour physical activity log can be used to record your physical activity for 7 days. There might be risk associated with walking on a treadmill. You will be provided instructions on how to get on and off treadmills and how to use the safety device. However, responsibility for using treadmill is assumed by you, the study participant.

**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 will contribute to future development of low-cost,
effective interventions that can be easily implemented and used to lower risk of gestational diabetes and obesity. If you are a member of the walking group and adhere to the prenatal physical activity guidelines (American College of Obstetrics and Gynecologists), you and your baby may receive health benefits.

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?
You will receive gifts of a recyclable grocery bag at week 10-14, a coffee mug at week 17-19, a t-shirt at week 27-29, an infant onesie and tote bag at week 34-36. Upon completion of all data collection and return of equipment, a finishing bonus of $250 will be awarded to you. You will also be provided with an additional $25 which may be used to purchase a $50 U.S. savings bond for your infant following successful completion of the postpartum data collection period. After completion of the 6-month and 1-year postpartum visits, you will receive an additional $40. The treadmill must be returned prior to the postpartum visit. The research team will be responsible for picking up the treadmill; however you will need to provide us with access. If you withdraw from the study or are no longer eligible to participate, you will receive the appropriate gifts for the time points completed, however, the treadmill must be returned. If for some reason you are medically unable as documented by your medical provider to continue with the walking program, and can complete the data collection periods you may still receive the finishing bonus (with the return of all necessary equipment). You will need to provide your social security number in order for us to process the finishing bonus.

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 (if applicable) in any way. 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.

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. Thelen Student Health Center, and/or referred to Mary Greeley Medical Center or another physician or medical facility at the location of the research activity. Compensation for any injuries will be paid if it is determined under the Iowa Tort Claims Act, Chapter 69 of the Iowa Code. Claims for compensation should be submitted on approved forms to the State Appeals Board and are available from the Iowa State University Office of Risk Management and Insurance.

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 project staff. This data will be kept on hand until the results of the study have been published in a locked file in the researcher's office (HNSB 1109). Identifiers will be kept separate from the data.
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 Dr. Christina Campbell, at 515-294-4280 or the study coordinator Kailing Kong, at 515-294-8673.

- 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 of Responsible Research, 1138 Pearson Hall, 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)

Parent Signature

Your signature indicates that you voluntarily agree to allow your child 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.

Parent’s Name (printed) ____________________________

(Parent’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)
APPENDIX C. M2M STUDY TIMELINE

The Blossom Project

Moms2Moves Study Timeline

Data Collection Period 1
- Screening: 00 a.m.
- Sign consent
- Medical History Form
- Medical provider release form
- Physical activity (PA) questionnaire

Data Collection Period 2
- 14-15 wk.: 40-120 min.
- Height, weight, and body composition
- Fasting blood sample
- Diet assessment
- PA assessment
- Provide participants with PA monitor to wear for 1 week

Data Collection Period 3, 4, 5
- 38, 38, 35 wk.: 90-120 min.
- Weight, and body composition
- Fasting blood sample
- Diet assessment
- PA assessment
- Provide participants with PA monitor to wear for 1 week

Walking Program Instructions
(Weeks: 12-15 until ≥ 35)
- 30 min.
- Walking protocols
- Walking diary
- Pedometer
- All participants should start the walking program by week 15

Data Collection Period 6
- 1 month post-delivery: 60 min.
- Maternal fasting blood sample
- Follow-up survey
- Infant's body composition
APPENDIX D. MEDICAL HISTORY FORM

Intervention 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 ______ mo Date of Birth: __________________________________________

Pre-pregnancy weight: __________ lbs Height: ______ ft ______ in

Handedness: Right OR Left

Is this your first pregnancy? Yes No

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/yr mo/day/yr mo/day/yr mo/day/yr mo/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 School  09  10  11  12
3. College     13  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 any medications on a regular basis? ________________
   If yes, please specify ________________

3. Have you taken medication regularly in the past? ________________
   If yes, please specify ________________
   How long ago was medication taken regularly? ________________

4. Do you currently take herbal supplements on a regular basis? ________________
   If yes, please specify ________________
   Have you in the past? ________________
   If so, how long ago? ________________

5. During your pregnancy are you consuming alcohol? ________________
   If so, how many drinks each week? ________________

Medical History (circle any, and give age at diagnosis):

<table>
<thead>
<tr>
<th>Disease</th>
<th>Age</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Diabetes</td>
<td></td>
</tr>
<tr>
<td>2. Thyroid Disease</td>
<td></td>
</tr>
<tr>
<td>3. Cirrhosis</td>
<td></td>
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<tr>
<td>4. Hepatitis</td>
<td></td>
</tr>
<tr>
<td>5. Gall Stones</td>
<td></td>
</tr>
<tr>
<td>6. Kidney Stones</td>
<td></td>
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<tr>
<td>7. Nephritis</td>
<td></td>
</tr>
<tr>
<td>8. Cancer (specify)</td>
<td></td>
</tr>
<tr>
<td>9. High Blood Pressure</td>
<td></td>
</tr>
<tr>
<td>10. Angina</td>
<td></td>
</tr>
<tr>
<td>11. Allergies (specify)</td>
<td></td>
</tr>
<tr>
<td>12. Goiter</td>
<td></td>
</tr>
<tr>
<td>13. Cardiovascular Disease</td>
<td></td>
</tr>
<tr>
<td>14. Depression requiring medication</td>
<td></td>
</tr>
<tr>
<td>15. Insomnia requiring medication</td>
<td></td>
</tr>
<tr>
<td>16. Gestational Diabetes</td>
<td></td>
</tr>
<tr>
<td>17. Preeclampsia</td>
<td></td>
</tr>
<tr>
<td>18. Previous infant with low birth weight</td>
<td></td>
</tr>
<tr>
<td>19. Early delivery with previous pregnancy</td>
<td></td>
</tr>
</tbody>
</table>
   If so, please explain: __________________
   __________________
   __________________
APPENDIX E. MEDICAL PROVIDER RELEASE FORM

Dear Medical Provider,

_________________________ has volunteered to participate in a study to better understand how walking may reduce gestational diabetes risk in overweight or obese pregnant women. During the study the participants will complete a maximum of 5 visits, including an informed consent meeting, a visit at each time point: 10-14, 18, 28, and 35 weeks gestation and one-month postpartum. At each of the gestational time points we will collect anthropometric, diet, physical activity data as well as a fasting blood sample.

Walking protocol:
The intervention will begin no earlier than wk 12 and no later than wk 15 and last until at least wk 35 or more. The participant will be provided a training session about the physical activity program to be implemented. The goal of our intervention is to add an additional 30 minutes of walking time above the mean walking time measured at baseline. The plan for increasing the amount of walking will be to increase walking by: 10 minutes/day in week 1; 20 minutes/day in week 2; and 30 minutes/day in week 3. Walking can be indoors (e.g. mall) or outdoors (e.g. park). A treadmill will be provided to increase adherence to the program. Depending on the length of each subject’s pregnancy, our goal of the intervention is to have all of the subjects complete at least 20 weeks of the walking program.

After completion of the physical activity program, participants will complete a follow-up meeting 1 month postpartum. They will provide a fasting blood sample and complete a final survey. This survey includes reporting the type of delivery, mother’s weight at her last prenatal visit as well as the infant’s weight, head circumference, length and APGAR scores at delivery. The infant’s body composition will also be measured using a PEAPOD during this visit.

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

- No prior history of gestational diabetes, chronic disease, lung or thyroid disorders;
- No physical restrictions to walking 30 min at a time.

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: 515-294-4260
Fax: 515-294-6193

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

Signature: __________________________ Date: ___________
APPENDIX F. THREE-DAY DIET RECORD INSTRUCTIONS

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

- 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- 30 g 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: kalling@iastate.edu or blossomproject@iastate.edu
Date: Wednesday, March 21, 2007

<table>
<thead>
<tr>
<th>Time</th>
<th>Food</th>
<th>Constituents</th>
<th>Description</th>
<th>Weight</th>
</tr>
</thead>
<tbody>
<tr>
<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>9am</td>
<td>Grape Nuts</td>
<td>Post Brand</td>
<td></td>
<td>120g</td>
</tr>
<tr>
<td>9am</td>
<td>Sugar</td>
<td>White</td>
<td></td>
<td>3g</td>
</tr>
<tr>
<td>9am</td>
<td>Milk</td>
<td>1%</td>
<td></td>
<td>106g</td>
</tr>
<tr>
<td>9am</td>
<td>Blueberries</td>
<td>Frozen, unsweetened</td>
<td></td>
<td>50g</td>
</tr>
<tr>
<td>9am</td>
<td>Orange Juice</td>
<td>Tropicana, no pulp, calcium added</td>
<td>120g</td>
<td></td>
</tr>
<tr>
<td>11:30 am</td>
<td>Almonds</td>
<td>Raw, unsalted, Kirkland brand</td>
<td>60g</td>
<td></td>
</tr>
<tr>
<td>1:00pm</td>
<td>Sandwich</td>
<td>Bread</td>
<td>Whole Wheat, Wheat Montana</td>
<td>45g</td>
</tr>
<tr>
<td>1pm</td>
<td>Sprouts</td>
<td>alfalfa</td>
<td></td>
<td>5g</td>
</tr>
<tr>
<td>1pm</td>
<td>Cheese</td>
<td>Tillamook Sharp Cheddar</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1pm</td>
<td>Ham</td>
<td>Hillshire Farms Honey Ham</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1pm</td>
<td>Cottage Cheese</td>
<td>Low fat 2% small curd</td>
<td></td>
<td>55g</td>
</tr>
<tr>
<td>1pm</td>
<td>Apple Juice</td>
<td>From concentrate, Apple Tree brand, 100% juice</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
APPENDIX G. SELF-EFFICACY QUESTIONNAIRES

Appendix C.6 – Barrier Self-efficacy Questionnaire

INSTRUCTIONS. Barriers are defined as anything that may stop you from doing physical activity. Please list four barriers to physical activity relevant to you, which you anticipate will occur in the next 6 WEEKS. An example is provided.

EXAMPLE:
Barrier: Lack of sleep

How confident you are in overcoming this barrier in the next 6 WEEKS? Please check one:

<table>
<thead>
<tr>
<th>0%</th>
<th>10%</th>
<th>20%</th>
<th>30%</th>
<th>40%</th>
<th>50%</th>
<th>60%</th>
<th>70%</th>
<th>80%</th>
<th>90%</th>
<th>100%</th>
</tr>
</thead>
<tbody>
<tr>
<td>not at all confident</td>
<td>somewhat confident</td>
<td>completely confident</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

BARRIER #1: _______

How confident are you in overcoming this barrier in the next 6 WEEKS? Please check one:

<table>
<thead>
<tr>
<th>0%</th>
<th>10%</th>
<th>20%</th>
<th>30%</th>
<th>40%</th>
<th>50%</th>
<th>60%</th>
<th>70%</th>
<th>80%</th>
<th>90%</th>
<th>100%</th>
</tr>
</thead>
<tbody>
<tr>
<td>not at all confident</td>
<td>somewhat confident</td>
<td>completely confident</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

BARRIER #2: _______

How confident are you in overcoming this barrier in the next 6 WEEKS? Please check one:

<table>
<thead>
<tr>
<th>0%</th>
<th>10%</th>
<th>20%</th>
<th>30%</th>
<th>40%</th>
<th>50%</th>
<th>60%</th>
<th>70%</th>
<th>80%</th>
<th>90%</th>
<th>100%</th>
</tr>
</thead>
<tbody>
<tr>
<td>not at all confident</td>
<td>somewhat confident</td>
<td>completely confident</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

BARRIER #3: _______

How confident are you in overcoming this barrier in the next 6 WEEKS? Please check one:

<table>
<thead>
<tr>
<th>0%</th>
<th>10%</th>
<th>20%</th>
<th>30%</th>
<th>40%</th>
<th>50%</th>
<th>60%</th>
<th>70%</th>
<th>80%</th>
<th>90%</th>
<th>100%</th>
</tr>
</thead>
<tbody>
<tr>
<td>not at all confident</td>
<td>somewhat confident</td>
<td>completely confident</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

BARRIER #4: _______

How confident are you in overcoming this barrier in the next 6 WEEKS? Please check one:

<table>
<thead>
<tr>
<th>0%</th>
<th>10%</th>
<th>20%</th>
<th>30%</th>
<th>40%</th>
<th>50%</th>
<th>60%</th>
<th>70%</th>
<th>80%</th>
<th>90%</th>
<th>100%</th>
</tr>
</thead>
<tbody>
<tr>
<td>not at all confident</td>
<td>somewhat confident</td>
<td>completely confident</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Task Self-efficacy Questionnaire:
HOW CONFIDENT ARE YOU THAT YOU WILL BE PHYSICALLY ACTIVE?

1. I feel confident that I will walk (for at least 30 minutes at my preferred pace) 1 day per week
   
   10% □ □ ○ ○ 20% □ □ ○ ○ 30% □ □ ○ ○ 40% □ □ ○ ○ 50% □ □ ○ ○ 60% □ □ ○ ○ 70% □ □ ○ ○ 80% □ □ ○ ○ 90% □ □ ○ ○ 100%

2. I feel confident that I will walk (for at least 30 minutes at my preferred pace) 2 days per week
   
   10% □ □ ○ ○ 20% □ □ ○ ○ 30% □ □ ○ ○ 40% □ □ ○ ○ 50% □ □ ○ ○ 60% □ □ ○ ○ 70% □ □ ○ ○ 80% □ □ ○ ○ 90% □ □ ○ ○ 100%

3. I feel confident that I will walk (for at least 30 minutes at my preferred pace) 3 days per week
   
   10% □ □ ○ ○ 20% □ □ ○ ○ 30% □ □ ○ ○ 40% □ □ ○ ○ 50% □ □ ○ ○ 60% □ □ ○ ○ 70% □ □ ○ ○ 80% □ □ ○ ○ 90% □ □ ○ ○ 100%

4. I feel confident that I will walk (for at least 30 minutes at my preferred pace) 4 days per week
   
   10% □ □ ○ ○ 20% □ □ ○ ○ 30% □ □ ○ ○ 40% □ □ ○ ○ 50% □ □ ○ ○ 60% □ □ ○ ○ 70% □ □ ○ ○ 80% □ □ ○ ○ 90% □ □ ○ ○ 100%

5. I feel confident that I will walk (for at least 30 minutes at my preferred pace) 5 days per week
   
   10% □ □ ○ ○ 20% □ □ ○ ○ 30% □ □ ○ ○ 40% □ □ ○ ○ 50% □ □ ○ ○ 60% □ □ ○ ○ 70% □ □ ○ ○ 80% □ □ ○ ○ 90% □ □ ○ ○ 100%

6. I feel confident that I will walk (for at least 30 minutes at my preferred pace) 6 days per week
   
   10% □ □ ○ ○ 20% □ □ ○ ○ 30% □ □ ○ ○ 40% □ □ ○ ○ 50% □ □ ○ ○ 60% □ □ ○ ○ 70% □ □ ○ ○ 80% □ □ ○ ○ 90% □ □ ○ ○ 100%

7. I feel confident that I will walk (for at least 30 minutes at my preferred pace) 7 days per week
   
   10% □ □ ○ ○ 20% □ □ ○ ○ 30% □ □ ○ ○ 40% □ □ ○ ○ 50% □ □ ○ ○ 60% □ □ ○ ○ 70% □ □ ○ ○ 80% □ □ ○ ○ 90% □ □ ○ ○ 100%

TOTAL SELF-EFFICACY SCORE:

Item 1 + Item 2 + Item 3 + Item 4 + Item 5 + Item 6 + Item 7 = Total Walking Self-Efficacy

□ □ □ □ □ □ □ = □ □
Thank you for your participation in the Blossom Project. Please take the time to complete this short questionnaire.

**Birth Outcome Questionnaire**

<table>
<thead>
<tr>
<th>Date Survey Completed: ____________________________</th>
</tr>
</thead>
</table>

At the end of your pregnancy you were considered:

- [ ] High risk
- [ ] Low risk
- [x] No risk

Why were you considered “at risk”?

How many weeks pregnant were you when you had your baby?

- [ ] 35 weeks
- [ ] 36 weeks
- [ ] 37 weeks
- [ ] 38 weeks
- [ ] 39 weeks
- [ ] 40 weeks
- [ ] More than 40 weeks
- [ ] Other: ____________________________

**Due Date**

Birth Date of Baby

<table>
<thead>
<tr>
<th>Sex of Baby (circle one)</th>
<th>Female</th>
<th>Male</th>
</tr>
</thead>
</table>

Birth Weight ____________ lb. ____________ oz.

**Head Circumference**

Length

<table>
<thead>
<tr>
<th>APGAR score</th>
<th>(1 minute)</th>
<th>(5 minutes)</th>
</tr>
</thead>
</table>

What was your body weight at your last prenatal visit? ____ lbs
What week of your pregnancy was your last prenatal visit? ____ week
Did you stop exercising before the birth of your baby?  Yes  No

If yes, circle the number of weeks prior to birth  1  2  3  4  5  6  7  8  9

Reason(s) why you stopped exercising?

<table>
<thead>
<tr>
<th>Type of delivery</th>
<th>Vaginal</th>
<th>Cesarean</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length of active labor (at least 4cm dilated pushing and contractions) (hrs, min)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Did you experience any complications during labor?  Yes  No

If yes, what where your complications
- Breech
- Epidural
- Induction
- Cesarean
- Stalled labor after 4cm dilation
- Difficulty pushing

Did you use any pain medications during labor?  Yes  No

If yes, what type?
- Epidural
- Narcotics (circle any that apply: Demerol, Nubain, or Stadol)
- Local Blocks
- Other
- Not sure

Did you have your labor induced?  Yes  No

If yes:
- Pitocin
- “Broke your water”

Will/are you breastfeeding?  Yes  No

If yes, did you have difficulty beginning breastfeeding?  Yes  No

Why?

Are you using infant formula?  Yes  No

If yes, why?

If yes what brand?
Did you take any supplements during pregnancy? Yes  No

If yes, what kind?
- Prenatal vitamin (Specify Brand):
- Herbal supplements
- Other

Did you consume fish during your pregnancy?  Yes  No

If yes, check average serving frequency that applies:
- 1/week
- 2/week
- 3/week
- Other (Specify amount per/week):

What type of fish did you consume during pregnancy:
- Tuna
- Albacore
- Cod
- Salmon
- Trout
- Other (Specify type):

If you chose not to consume fish during your pregnancy check any reasons that may apply:
- I don’t like fish
- I couldn’t eat the fish due to nausea
- Mercury contamination concerns
- Food Safety issues (food poisoning)
- Costs too much money
- Other (Specify type):

Did you consume any of the following foods during pregnancy?
- Soy milk fortified with DHA/Omega-3
- Eggs fortified with Omega-3s
APPENDIX I. BLOOD PROFILES OF PARTICIPANTS

Blood profiles of participants at all gestational time point and one month post-partum

<table>
<thead>
<tr>
<th>Variables</th>
<th>Overweight</th>
<th>Obese</th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Intervention</td>
<td>Control</td>
<td>Intervention</td>
<td>Control</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>V1 (10 - 14 weeks of gestation)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>n = 9</td>
<td>87.1 ± 3.8</td>
<td>86.9 ± 6.1</td>
<td>86.1 ± 5.7</td>
<td>86.6 ± 4.8</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Glucose (mg/dL)</td>
<td>n = 10</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>121.7 ± 57.8</td>
<td>91.0 ± 30.9</td>
<td>150.0 ± 62.0</td>
<td>121.8 ± 36.6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Triacylglycerides (mg/dL)</td>
<td>n = 9</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>62.4 ± 10.6</td>
<td>64.9 ± 10.1</td>
<td>61.3 ± 10.1</td>
<td>61.7 ± 10.2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>HDL (mg/dL)</td>
<td>n = 9</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>92.8 ± 12.2</td>
<td>94.8 ± 33.4</td>
<td>103.2 ± 19.8</td>
<td>112.0 ± 32.3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>LDL (mg/dL)</td>
<td>n = 9</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>179.7 ± 10.9</td>
<td>177.9 ± 40.1</td>
<td>194.6 ± 25.8</td>
<td>197.8 ± 36.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total cholesterol (mg/dL)</td>
<td>n = 9</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Iron (mcg/dL)</td>
<td>n = 9</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>V2 (17 - 19 weeks of gestation)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>n = 9</td>
<td>84.7 ± 6.5</td>
<td>84.1 ± 3.8</td>
<td>83.7 ± 9.6</td>
<td>83.5 ± 5.6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Glucose (mg/dL)</td>
<td>n = 10</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>162.3 ± 59.8</td>
<td>131.4 ± 47.7</td>
<td>201.9 ± 76.7</td>
<td>156.9 ± 43.9</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Triacylglycerides (mg/dL)</td>
<td>n = 9</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>66.9 ± 10.6</td>
<td>64.5 ± 12.8</td>
<td>61.0 ± 8.3</td>
<td>64.9 ± 15.6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>HDL (mg/dL)</td>
<td>n = 9</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>106.9 ± 14.9</td>
<td>108.4 ± 32.2</td>
<td>106.3 ± 17.3</td>
<td>111.8 ± 37.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>LDL (mg/dL)</td>
<td>n = 9</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>206.3 ± 23.5</td>
<td>199.1 ± 39.2</td>
<td>207.7 ± 23.9</td>
<td>208.0 ± 39.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total cholesterol (mg/dL)</td>
<td>n = 9</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Iron (mcg/dL)</td>
<td>n = 9</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>V3 (27 - 29 weeks of gestation)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>n = 9</td>
<td>86.0 ± 7.1</td>
<td>83.0 ± 5.3</td>
<td>81.3 ± 8.6</td>
<td>86.3 ± 6.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Glucose (mg/dL)</td>
<td>n = 7</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>185.8 ± 53.7</td>
<td>168.1 ± 33.6</td>
<td>245.4 ± 84.4</td>
<td>216.5 ± 79.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Triacylglycerides (mg/dL)</td>
<td>n = 8</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>75.9 ± 12.7</td>
<td>75.3 ± 13.6</td>
<td>68.1 ± 7.5</td>
<td>64.0 ± 17.4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>HDL (mg/dL)</td>
<td>n = 6</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>133.8 ± 31.0</td>
<td>143.4 ± 42.9</td>
<td>129.7 ± 27.8</td>
<td>132.2 ± 34.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>LDL (mg/dL)</td>
<td>n = 6</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>246.8 ± 39.1</td>
<td>252.4 ± 40.2</td>
<td>247.9 ± 25.7</td>
<td>239.3 ± 35.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total cholesterol (mg/dL)</td>
<td>n = 6</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Iron (mcg/dL)</td>
<td>n = 6</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>V4 (34 - 36 weeks of gestation)</td>
<td>V5 (1-month post-partum)</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>---------------------</td>
<td>---------------------------------</td>
<td>--------------------------</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>n = 9</td>
<td>n = 7</td>
<td>n = 8</td>
<td>n = 6</td>
<td>n = 6</td>
<td>n = 5</td>
</tr>
<tr>
<td>Glucose (mg/dL)</td>
<td>82.7 ± 9.5</td>
<td>83.4 ± 2.9</td>
<td>85.6 ± 8.4</td>
<td>89.3 ± 6.2</td>
<td>88.7 ± 6.3</td>
<td>88.0 ± 6.6</td>
</tr>
<tr>
<td>Triacylglycerides (mg/dL)</td>
<td>221.6 ± 61.0</td>
<td>207.1 ± 80.6</td>
<td>275.1 ± 79.2</td>
<td>242.2 ± 79.2</td>
<td>130.8 ± 77.5</td>
<td>96.5 ± 58.5</td>
</tr>
<tr>
<td>HDL (mg/dL)</td>
<td>67.1 ± 11.3</td>
<td>68.0 ± 17.5</td>
<td>65.5 ± 8.7</td>
<td>64.0 ± 12.2</td>
<td>48.2 ± 8.1</td>
<td>59.5 ± 9.4</td>
</tr>
<tr>
<td>LDL (mg/dL)</td>
<td>137.0 ± 42.6</td>
<td>140.9 ± 33.9</td>
<td>133.0 ± 35.4</td>
<td>127.7 ± 42.9</td>
<td>110.3 ± 15.2</td>
<td>129.2 ± 37.3</td>
</tr>
<tr>
<td>Total cholesterol (mg/dL)</td>
<td>248.4 ± 50.1</td>
<td>250.4 ± 43.2</td>
<td>252.8 ± 30.6</td>
<td>240.2 ± 41.4</td>
<td>184.5 ± 16.7</td>
<td>208.0 ± 44.8</td>
</tr>
<tr>
<td>Iron (mcg/dL)</td>
<td>57.9 ± 14.3</td>
<td>98.0 ± 29.2</td>
<td>71.6 ± 35.9</td>
<td>72.8 ± 32.8</td>
<td>61.2 ± 10.5</td>
<td>95.2 ± 21.8</td>
</tr>
</tbody>
</table>

Values shown are mean ± SD

HDL = high-density lipoprotein; LDL = low-density lipoprotein