DO BEHAVIOURAL AND FAMILY-RELATED FACTORS INFLUENCE THE LIKELIHOOD OF MEETING GESTATIONAL WEIGHT GAIN RECOMMENDATIONS, AND CAN THE *SMARTMOMS CANADA* APPLICATION ASSIST WITH WEIGHT GAIN MANAGEMENT AND IMPROVE BEHAVIOURS DURING PREGNANCY?

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DEDICATION

This dissertation is dedicated to my father-in-law, Davi da Silva, who passed away earlier this summer. Davi, thank you for welcoming me as your daughter since the first time we met.

You will always be present in our lives.

"Everything is possible for one who has faith." (Mark 9:23)

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ABSTRACT

A healthy *in utero* environment is essential for achieving optimal outcomes for women and their children. Gestational weight gain (GWG) has been shown to impact current and future maternal-infant health outcomes. Suboptimal weight gain during pregnancy (defined by the Institute of Medicine GWG guidelines) has been linked to several complications and is implicated in the inter-general cycle of obesity. Understanding contributors to GWG and intervening during pregnancy with healthy behaviour strategies may have a multi-generational effect for chronic disease prevention. The objective of the first study of this thesis was to examine the association between i) eating habits during pregnancy, ii) advice from family or friends about GWG, and iii) personal effort to stay within weight gain limits, and meeting GWG recommendations. Cross-sectional data were collected from pregnant and postpartum women who responded to the validated electronic maternal (EMat) health survey. Regardless of receiving advice about GWG, women self-reporting less healthy eating habits in pregnancy than before pregnancy, receiving advice from family/friends about GWG, and lower personal effort to stay within guidelines, had an increased odds of weight gain discordant with recommendations. The objective of the second study was to assess the short-term effect of the *SmartMoms Canada* application (app) usage on promoting adequate GWG and healthy behaviours. *SmartMoms Canada* is an app-based intervention designed to help pregnant women adhere to GWG guidelines and improve healthful behaviours. Pregnant women using the *SmartMoms Canada* app more frequently had a higher moderate-to-vigorous physical activity daily average when compared with women with a lower usage. Together, the EMat and *SmartMoms* results from this thesis contribute to identifying and mitigating potential factors associated with discordant GWG and healthy behaviours.

AUTHOR CONTRIBUTIONS

The electronic maternal (EMat) health survey was previously developed and validated by the Adamo research team. Data collection was finalized before this thesis was initiated. Sara C. S. Souza was responsible for the conceptualization of the EMat study (article 1) presented in this thesis as well for data analysis and writing of the published manuscript. With regards to the *SmartMoms Canada* study (article 2), Sara was involved in the testing phase of the application (app), intensely provided feedback to the app developers, assisted with ethics renewal and modifications, and provided training to researchers from other sites and volunteers regarding the app procedures for installation and use. Sara was also in charge of the recruitment of participants, data collection and management, data analysis, and writing of the final manuscript.

As thesis supervisor, Dr. Kristi B. Adamo guided the overall process associated with all studies included in the present thesis by providing incredible methodological support, revisions, input, and suggestions. Drs. Danilo F. da Silva and Taniya S. Nagpal, postdoctoral fellows of the Adamo research team, are additional co-authors on both studies of this thesis. They have assisted with conceptual guidance in the project planning stages and reviewed the final manuscripts. Dr. da Silva has also provided statistical analysis support.

Dr. Zachary M. Ferraro, Kevin Semeniuk, Dr. Leanne Redman, and Dr. Garry Shen, a former PhD student of the Adamo research team, the research coordinator of the *SmartMoms Canada* project, the principal investigator of the *SmartMoms* in the United States, and the research collaborator from the Manitoba site respectively, are additional co-authors of the *SmartMoms Canada* manuscript. Dr. Ferraro, Mr. Semeniuk, Dr. Redman, and Dr. Shen have reviewed and provided input and suggestions that strength the final manuscript.

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ABBREVIATIONS

GWG	Gestational Weight Gain
IOM	Institute of Medicine
LGA	Large for Gestational Age
SGA	Small for Gestational Age
BMI	Body Mass Index
mHealth	Mobile Health
app	Application
HCP	Health Care Providers
OR	Odds Ratio
CI	Confidence Interval
RR	Relative Risk
PSQI	Pittsburgh Sleep Quality Index
EMat	Electronic Maternal
SCT	Social Cognitive Theory
HRQoL	Health-Related Quality of Life

CHAPTER 1

1.1 INTRODUCTION

The physiological demands of pregnancy operate as a stress test for life,[1] and unfortunately, developing complications throughout this period can impact current and future maternal-infant health outcomes.[2,3] In 1990, Dr. David Barker started reporting epidemiological findings highlighting the importance of long-term programming in early life that begins *in utero*.[4] A multitude of different study designs and outcomes have indicated that the intrauterine environment may be associated with downstream diseases.[5] An important marker during pregnancy associated with maternal health and fetal development is gestational weight gain (GWG).

Women who gain weight suboptimally during pregnancy (defined by Institute of Medicine [IOM] GWG recommendations)[6] are at risk of several health complications such as hypertensive disorders of pregnancy,[7] large- and small-for-gestational-age (LGA and SGA respectively) neonates[8] as well as the perpetuation of an inter-generational cycle of obesity.[6,9-13] Annually, almost 70% of pregnant women in Canada are outside the IOM GWG guidelines at the end of their pregnancy.[14] Evidence from systematic reviews summarizes that lifestyle interventions during pregnancy have the potential to prevent women from gaining above or below GWG recommendations,[15-19] experiencing postpartum weight retention[15,19] and developing perinatal complications (e.g., preeclampsia and gestational diabetes).[20,21]

The magnitude of energy imbalance is an important factor in achieving adequate GWG, and consequently, other more favourable pregnancy outcomes.[22] This magnitude of energy imbalance will depend on the association between energy intake, energy expenditure (necessary to support maternal and fetal metabolism), and energy storage (fetal growth and accumulation of energy depots during pregnancy). Energy intake requirements during pregnancy are defined as dietary intake necessary to supply energy expenditure as well as to promote optimal fetal development and accommodate for specific maternal adaptations during pregnancy (e.g., breast tissue, uterus, placenta).[6] Individual pregravid weight and physiological demands of pregnancy in each trimester may differentiate energy requirements between women and must be considered for GWG management.[22]

Eating behaviours, such as restrained eating and cravings, have been associated with the risk of suboptimal GWG.[23] A systematic review looking at macronutrient composition and GWG found a consistent small-to-moderate association between higher energy intake and excessive weight gain during pregnancy.[24] GWG may also vary according to physical activity levels. Although GWG can be managed by being active,[15] less than 30% of women are considered physically active throughout pregnancy.[25] Women spend over 50% of their day sedentary during pregnancy, and this number increases as gestation progresses.[26] Pregnant women also face challenges related to their sleep patterns, as sleep duration is habitually lower than non-pregnant women.[27] Fewer hours of sleep during pregnancy are associated with higher blood glucose levels, and maternal fat gain.[28,29]

Plante *et al*.[23] proposed a relationship model in which psychosocial factors are also indicated as important components indirectly contributing to GWG. Psychosocial factors that have been described as key predictors of GWG include social context, negative body image, and personal efforts/attitudes toward weight.[23,30-32] Recently, work from our research team[33] showed that more than half of women self-reported that they were not making a conscious effort to meet GWG recommendations. Our research group has also identified that women with low self-efficacy, and external locus of control (e.g., weight gain perception as beyond their control) were less likely to achieve guideline-concordant GWG.[34]

Randomized controlled trial evidence shows that an in-person lifestyle intervention may increase physical activity levels of women entering pregnancy with a normal body mass index (BMI) or previously physically active; however, this intervention-effect is dependent on participants' adherence to the exercise program among women who have an overweight/obesity pre-pregnancy BMI and were inactive before pregnancy.[35] Exploratory analyses from an intervention to manage GWG through physical activity and nutritional information reported significant lower energy intake pre- and post-intervention in women with pre-pregnancy overweight/obesity.[36] A recent systematic review of meta-analyses showed a consistent association between decreased GWG mean and physical activity/diet interventions.[37] During the COVID-19 pandemic, virtual exercise group programs were also created to improve maternal outcomes during pregnancy.[38] However, group or in-person interventions do not typically provide timely personalized advice to participants and have limited scalability. Financial limitations and geographical barriers may also prevent many women from achieving adequate GWG and healthful behaviours.

An alternative model for delivering interventions to promote optimal GWG and behaviours throughout pregnancy is the mobile health (mHealth) approach, which is valuable for addressing healthy eating and increasing physical activity levels in pregnant women.[39-41] Systematic reviews have demonstrated that mHealth programs designed for a non-pregnant population can help participants make behavioural changes and subsequently, manage their weight.[42,43] mHealth tools offer many benefits, including being interactive and offering personalized options. Additionally, mHealth can be delivered anywhere at a time most convenient for the user, thus offering potential cost-effectiveness and eliminating time or accessibility barriers.[39,44,45] Although the availability of applications (apps) designed to improve physical activity is increasing, the quality and use of evidence-based information to build these tools are still low.[46] There is a lack of readily available and cost-effective mHealth options providing access to evidence-based information to manage GWG, nutrition, physical activity, and sleep for pregnant women.

1.2 INTRAUTERINE ENVIRONMENT AND GESTATIONAL WEIGHT GAIN

Several physiological adaptations occur in a woman's body during pregnancy that may impact future maternal and neonate health.[47] The fetal development and adaptions occurring in the intrauterine environment can lead to early programming that may influence prenatal growth and postnatal metabolism and disease risk, such as obesity.[4] Obesity is a chronic disease defined by excessive fat accumulation that represents a risk to health.[48] Besides the global adult obesity epidemic, the percentage of children living with obesity is increasing worldwide.[49] In 2019, the number of children under the age of 5 years with obesity or overweight in the world was estimated to be 38.2 million (~5%).[48] Children living with obesity may experience disorders such asthma[50] and fatty liver disease.[51] Obesity during childhood or early life is also a risk factor for long-term chronic diseases.[52,53] Childhood obesity is a current public health challenge. A set of global targets aiming to prevent early life obesity are in place in several countries.[54] To mitigate this epidemic, guidelines on physical activity, sedentary behaviour and sleep have been developed for children.[55] However, systematic review evidence from animal studies,[56] observational cohorts[57], and interventions[58] show that the intrauterine environment influenced by maternal conditions including pre-pregnancy BMI[59] and GWG[9] may increase the risk of overweight and obesity across childhood. The findings from Voerman *et al*.[9] suggest that excessive GWG is associated with 39-72% increased risk of overweight throughout childhood. Therefore, periconceptional and pregnancy factors should be also considered in the prevention of obesity.

Excessive GWG has been associated with risk of obesity in young children.[60] Complications of suboptimal GWG include SGA or LGA neonates, high postpartum weight retention, and subsequent downstream obesity in women and their infants.[61,62] While GWG is an expected outcome of pregnancy, gaining too little or too much weight may negatively affect the health of both women and their children. In 2009, the IOM released a re-examined version of the weight gain during pregnancy guidelines[6] to reflect the demographic changes observed in obstetric populations since 1990. These updated guidelines provide a recommended total and weekly ranges of GWG according to women's pre-pregnancy BMI (Table 1).

Table 1. 2009 Institute of Medicine Weight Gain Guidelines using pre-pregnancy BMI

	Total Weight Gain		Rates of Weight Gain* 2nd and 3rd Trimester	
Pre-pregnancy BMI	Range in kg	Range in lbs	Mean (range) in kg/week	Mean (range) in lbs/week
Underweight (<18.5 kg/m^2)	12.5-18	28-40	0.51 (0.44-0.58)	1 (1-1.3)
Normal weight (18.5-24.9 kg/m^2)	11.5-16	25-35	0.42 (0.35-0.50)	1 (0.8-1)
Overweight (25.0-29.9 kg/m^2)	7-11.5	15-25	0.28 (0.23-0.33)	0.6 (0.5-0.7)
Obese (≥30.0 kg/m^2)	5-9	11-20	0.22 (0.17-0.27)	0.5 (0.4-0.6)

BMI: Body Mass Index. *Calculations assume a 0.5-2 kg (1.1-4.4 lbs) weight gain in the first trimester.

The prevalence of women gaining above or below the GWG guidelines in Canada is around 50% and 20%, respectively.[11,14] Women falling outside weight gain recommendations during pregnancy experience metabolic and physiological changes that may result in adverse outcomes (e.g., gestational hypertension, preeclampsia, and gestational diabetes) associated with premature cardiovascular disease[63,64] and increased risk of metabolic and vascular diseases in later life.[3] Women with pre-pregnancy overweight and obesity are at greater risk of exceeding their weight gain recommendations given the smaller absolute range.[65] Excessive GWG has been found to be a significant predictor of postpartum weight retention and long-term weight gain in women after pregnancy.[66-68] Women who fall above GWG guidelines are more likely to enter subsequent pregnancies at a higher body weight,[69-71] putting themselves and the fetus at greater risk of complications.[72] Although excessive GWG is more prevalent, gaining below guidelines (i.e., inadequate GWG) is also associated with several downstream risks, such as premature birth, and SGA neonates.[23,73] Thirty-six randomized trials including data from 16 countries were recently combined by the International Weight Management in Pregnancy collaborative group and showed that women who exceed GWG guidelines have an increased risk of cesarean section and delivering LGA neonates. On the other hand, women who gained inadequate weight had a higher odds of preterm birth and SGA neonates when compared to women who met the guidelines.[8] Therefore, optimizing guideline-concordant GWG is essential in improving maternal-fetal health outcomes.

1.3 BEHAVIOURS DURING PREGNANCY

1.3.1 Eating

Adequate nutrition with a balanced diet, including both micro- and macro-nutrients, is essential for healthy fetal development.[74] Malnutrition, either under- or overnutrition, has been shown to impact fetal metabolic pathways and increase the risk of childhood and adult diseases beyond the neonatal period.[74,75] Poor maternal dietary habits throughout pregnancy have also been linked to a higher likelihood of postpartum weight retention.[76]

The energy intake requirements during pregnancy represent those necessary to sustain adequate development of maternal tissues (e.g., breast, uterus, placenta) and the fetus.[6] These requirements involve the energy intake necessary to support the energy expended by women and their fetus and to guarantee sufficient energy to support the process of fetal and maternal tissue growth. Regardless of the pre-pregnancy BMI, women are expected to gain between 0.5 and 2.0 kg until 13 gestational weeks.[6] Based on a conservative estimation of the energy density associated with overall weight gain, a greater amount of ~40.7-162.6 kcal/day may be required for weight gain in the first trimester.[77,78] However, studies are lacking that detail the specific composition of GWG during early pregnancy. What is known is that gaining more fat mass will increases energy requirements to a larger extent.[79,80]

In general, pregnant women are required to increase their caloric intake by approximately 340 and 450 kcal per day during the second and third trimesters, respectively.[6] This increase in the energy requirements is primarily due to weight gain and higher metabolic rate associated with maternal cardiac output and fetal metabolism throughout mid and late pregnancy.[22] However, a study evaluating energy balance during pregnancy stated that the mobilization of maternal fat mass in pregnant women with obesity compensates for the energy demand produced by the pregnancy and growing fetus.[22,81] Delivering information about nutrition to pregnant women should be individualized, accounting for the woman's activity level, pre-pregnancy BMI, and optimal GWG.

1.3.2 Physical activity

Physical activity during pregnancy is safe for women without specific contraindications to exercise.[82,83] Like the general population, adopting or continuing an active lifestyle is highly beneficial for pregnant women.[11,83] Regular physical activity improves many pregnancy outcomes, such as better weight management, reduced risk of gestational diabetes, and improved psychological health.[20,83-85] Pregnant women without contraindications to exercise should be encouraged by their health care providers (HCP) to engage in physical activity practices to support maternal and fetal health.[82,86,87] Contraindications to exercise during pregnancy include pre-conceptional conditions (e.g., uncontrolled type I diabetes and hypertension) and complications developed during gestation such as preeclampsia and placenta praevia.[83]

From 24 meta-analyses exclusively focused on physical activity interventions, 19 reported a significant decrease of mean GWG.[37] The risk of developing gestational diabetes for women exposed to physical activity interventions during pregnancy is also reduced with reported odds ratio (OR) of 0.33 (95% confidence interval [CI]=0.14-0.76)[88] to relative risk (RR) equal to 0.83 (95% CI=0.69-1.00)[89] in the current literature. Other than maternal outcomes, substantial meta-analysis evidence illustrates that leisure-time physical activity during pregnancy is associated with a lower likelihood of LGA neonates.[90]

The Canadian Society for Exercise Physiology and the Society of Obstetricians and Gynaecologists of Canada and Health Canada provided evidence-based recommendations through the '*2019 Canadian Guideline for Physical Activity throughout Pregnancy*', regarding exercise during pregnancy in the promotion of maternal, fetal and neonatal health.[83] In summary, regular physical activity is safe, beneficial in managing GWG, and may prevent maternal and fetal comorbid conditions.[11,15,91] Given that pregnant women often do not receive appropriate information or guidance about exercise during the prenatal period,[92] the access to evidence-based physical activity recommendations during pregnancy is imperative to help women achieve healthy outcomes. New intervention designs should focus on providing a cost-effective and frequent delivery of physical activity information that will help pregnant women to adhere to and maintain an active routine.

1.3.3 Sleep

Pregnancy changes associated with maternal diet and physical activity level are well established; however, physiological modifications during pregnancy are also associated with sleep.[47] Although sleep patterns during pregnancy are typically similar to those in non-pregnant women,[93] there are important differences to be considered.[94] Data collected via polysomnography (i.e., sleep study) in perinatal women showed an increase in awake times, differences in total sleep time (compared to those in non-pregnant women and across pregnancy), an increase in slow-wave sleep, and a decrease in REM sleep across pregnancy.[95-98] In general, total sleep time decreases from the first to third trimester, and sleep duration is shorter during gestation, when compared with the non-pregnancy period.[27,99]

Disordered sleep during pregnancy is expected, but the risk of developing maternal or fetal complications associated with poor sleep is not well publicized, and should be addressed by HCP.[100] Approximately 12% of pregnant women are affected by insomnia in early pregnancy, with rates as high as 75% in late pregnancy.[101,102] The risk of obstructive sleep apnea-hypopnea increases from 10% in mid-pregnancy to 90% in the late period.[103,104] There is a lack of information available in the literature on the physiological consequences associated with poor sleep; however, research suggests that overall poor sleep during pregnancy may increase inflammatory and cell stress pathways.[105]

Five dimensions of sleep health have been proposed: 1) Subjective satisfaction; 2) Appropriate timing; 3) Adequate duration; 4) High efficiency; and 5) Sustained alertness during waking hours.[106] One third of the studies identified by Ladyman and Signal[107] in a scoping review about sleep health and pregnancy have used the Pittsburgh Sleep Quality Index (PSQI) to measure sleep quality. It is expected that women will have a higher prevalence of poor sleep quality (PSQI≥5) than men, with an PSQI average equal to 5.7 (PSQI range: 0-21).[108] For instance, a meta-analysis evidence reported a PSQI average during overall pregnancy of 6.07 and that 45.7% pregnant women experience poor sleep quality with an increase of 1.68 in the PSQI average between second and third trimesters.[109]

Poor sleep quality during early pregnancy has been associated with birth complications such as premature rupture of membranes (adjusted RR=1.12, 95% CI=1.00-1.25).[110] In late pregnancy, lower sleep quality and shorter sleep have been associated with increased maternal fat gain.[29] Fewer hours of sleep is also linked to higher glucose levels.[28] Sleep disturbances during pregnancy, including poor sleep quality, extreme sleep duration, insomnia symptoms, restless legs syndrome, subjective sleep-disordered breathing and diagnosed obstructive sleep apnea, are associated with high risk of several maternal and fetal complications, such as preeclampsia (OR=2.80, 95% CI=2.38-3.30), gestational hypertension (OR=1.74, CI 95%=1.54-1.97), gestational diabetes (OR=1.59, 95% CI=1.45-1.76), cesarean section (OR=1.47, 95% CI=1.31-1.64), preterm birth (OR=1.38, 95% CI=1.26-1.51), LGA neonates (OR=1.40, 95% CI=1.11-1.77), and stillbirth (OR=1.25, 95% CI=1.08-1.45).[111]

Mind-body interventions (e.g., mindfulness, yoga) have been effective in helping other populations improve sleep.[112,113] However, their impact is still unknown in pregnant women. A recent systematic review on interventions for sleep problems during pregnancy reported a lack of studies focused on improving sleep quality in these women.[114] Since most sleep problems are amenable to treatment, the adoption of new strategies to promote sleep health during pregnancy is needed to prevent adverse maternal and fetal outcomes. One potential alternative is the use of mHealth intervention programs.

1.4 WHY A MOBILE HEALTH INTERVENTION?

Pregnant women have reported receiving insufficient guidance and often no information on healthy behaviours from HCP.[115-118] Meanwhile, HCP also lack simple, evidence-based tools to support counselling on healthy weight gain.[119] Reaching the population using only in-person provider-based delivery of weight management is challenging and could strain the current health care system. Thus, new, creative methods for delivering health information are needed, and mHealth may be an ideal modality. Fortunately, Canada is the world leader in online engagement and smartphone penetration, with 99% of the population having access to wireless networks and 90% owning a mobile phone.[120,121] At least one smartphone app is used by more than 80% of women in their childbearing years.[120] In 2012, 96% of pregnant women had already indicated interest in receiving guidance on prenatal care through their phone.[122] Women are seeking personalized support to assist them in staying within their GWG targets and are receptive to novel approaches.[123]

A substantial body of evidence suggests a key role for physical activity, diet, and mixed approach interventions in the promotion of adequate GWG.[21] Nevertheless, these interventions may be costly and time-consuming for both HCP and patients. A cost-effective alternative to overcoming limitations of standard prenatal care is the adoption of mHealth tools.[124,125] Web-based interventions, as a stand-alone service or as an initial program in a stepped care model with more intensive in-person services, are considered a cost-effective option for health care dissemination.[126]

According to the United Nations, 6 of 7 billion people worldwide have a mobile phone subscription.[127] Mobile devices are widely used by pregnant women[120,128] and the implementation of interventions through these technologies can provide ‘real-time’ and personalized care. A systematic review on digital health interventions targeting diet, physical activity, and weight gain during pregnancy extracted 11 studies between 2012 and 2020.[129] Three app-based studies were identified[130-132] and their main outcomes included GWG[130,132] and physical activity[131]. No Canadian mHealth intervention using an app to manage GWG and healthy behaviours throughout pregnancy was reported (all studies conducted in the United States).

Although one pilot study by Choi *et al.*[131] aiming to increase physical activity during pregnancy through a mHealth program found no statistically significant differences between intervention and control groups; participants seem to accept the use of an app to promote physical activity. The literature is inconsistent regarding the effectiveness of mHealth interventions to reduce excessive GWG. Dahl *et al.*[130] have found that the use of a mobile app may facilitate healthy behaviour change; however, the effect of the intervention on preventing discordant GWG was not significant. In contrast, the study performed by Redman *et al*. identified that fewer women in the mHealth intervention group exceeded guidelines compared to the standard care control group.[132]

Recent research has shown that pregnant women, regardless of socioeconomic level or ethnicity, are willing to use dietary and exercise information from digital interventions to assist them with engaging in a healthy lifestyle.[133] Women in the perinatal period are consistently looking for 'right time' information and hope that mHealth tools will help HCP accessing their data.[134] Recommendations from mHealth tools to help women meet the guidelines for weight gain during pregnancy have been considered valuable by users[135] and are associated with decreasing GWG in participants living with overweight and obesity before pregnancy.[136]

CHAPTER 2

2.1 RATIONALE AND RELEVANCE OF STUDY

Weight management and adoption of healthful behaviours in pregnancy are an important intervention target, especially as women who have difficulty adhering to these practices place themselves and their children at increased health risks. Pregnancy represents the ideal period for the prevention of chronic diseases. Energy intake requirements during pregnancy should provide additional energy to achieve appropriate rates of GWG and, consequently, optimal fetal and maternal tissue growth. Researchers postulate that there is a robust link between gaining weight outside the recommendations, poor dietary behaviours, and lack of nutrition knowledge. Increasing physical activity levels during pregnancy can, among other health benefits, improve GWG outcomes, though few women are considered physically active throughout pregnancy. Pregnant women also face challenges related to their sleep patterns, as sleep duration is habitually lower than non-pregnant women.

Addressing weight management issues during pregnancy is challenging, and doing so practically and effectively, requires the identification and targeting of potential contributors to discordant GWG. Moreover, knowing that in-person/face-to-face provider-based delivery of weight management interventions has been impractical for reaching a national population, it is necessary to test alternative approaches to target behaviours contributing to a healthy pregnancy, including GWG. As such, this thesis investigates correlates of GWG using two strategies. First, data from the Electronic Maternal (EMat) health survey, designed to identify and explore pregnancy behaviours related to GWG, were examined to analyze the association between (i) eating habits during pregnancy, (ii) advice from family or friends about GWG, and iii) personal effort to stay within weight gain limits, and meeting GWG recommendations. Second, we analyzed potential benefits offered by our team's recently developed *SmartMoms Canada* mHealth program. The *SmartMoms Canada* intervention responds to the gap of readily available access to evidence-based and personalized information to promote healthy lifestyle for pregnant women. In combination, data gathered from these studies help inform future interventions that will assist with healthful behaviours and weight gain management during pregnancy.

2.2 THESIS OBJECTIVES

Considering the maternal-fetal health risks associated with gaining above or below GWG guidelines, this thesis project aimed to:

1) Analyze the association between i) eating habits during pregnancy, ii) advice from family or friends about GWG, and iii) personal effort to stay within weight gain limits, and meeting GWG recommendations using a previously validated questionnaire called the EMat health survey.
2) Assess the effectiveness of the *SmartMoms Canada* mHealth program in helping women achieve adequate GWG and adhere to healthful behaviours related to nutrition, physical activity, and sleep.

2.3 THE ELECTRONIC MATERNAL HEALTH SURVEY

The EMat health survey is a comprehensive questionnaire designed to examine factors that may impact GWG (i.e., contributors to weight management).[137] A vigorous methodology was adopted for the development of this questionnaire with a panel of experts to validate its content. The EMat survey was based on the following six constructs: 1) Health Practices, 2) Pregnancy Weight, 3) Physical Activity, 4) Diet, 5) Pregnancy Intentions, and 6) Diet and Weight Gain Perceptions.[137] For the present thesis analysis, specific questions about GWG counselling by HCP (construct 1), weight self-perception and social network advice (construct 2), and general diet habits (construct 4) were analyzed.

The psychological theoretical framework selected to develop this comprehensive questionnaire was the Social Cognitive Theory (SCT).[138] This theory outlines the association between predictive and modifiable factors and behaviour change.[32] The main concept in SCT is reciprocal determinism,[138] which is a response from the interaction of individual experiences, behaviour, and social context. Heath behaviour studies considered five main components within the SCT as modifiable: 1) Self-efficacy, 2) Locus of control, 3) Perceived barriers, 4) Outcome expectations, and 5) Social environment.[138] These variables guided the inclusion of questions related to key psychological predictors of GWG in the EMat survey.

The target population of this maternal health questionnaire was pregnant or postpartum women. Inclusion criteria for eligibility in the EMat study were: i) reporting a live birth in the year after the 2009 IOM guidelines[6] were published, ii) aged 18 years or older, and iii) expecting a single fetus. Reponses were collected between 2014-2018 and captured in the REDCap™ secure data tool.

2.4 SMARTMOMS CANADA

The *SmartMoms Canada* app represents a mHealth intervention program delivering real-time prenatal weight management and healthy behaviours guidance and support. The primary objective of this intervention is to assess the effectiveness of the *SmartMoms Canada* program in helping women adhere to GWG guidelines and prevent pregnancy-related complications. This mHealth intervention also aims to assess program feasibility, and determine to what degree the *SmartMoms Canada* app impacts the adoption of healthful behaviours related to nutritional, physical activity and sleep habits, improves health-related quality of life (HRQoL), and symptoms of depression. Inclusion criteria are being a pregnant woman, aged between 18-40 years, carrying a single fetus, with pregravid BMI between 18.5 and 39.9 kg/m^2, less than or equal to 20 weeks of gestation, and living in Canada.

The *SmartMoms Canada* app provides automated, tailored feedback that is based on the IOM guidelines,[6] various national evidence-based pregnancy-related guidelines, and considers participant data gathered from Wi-Fi enabled accessories (Fitbit® device, Withings® scale). *SmartMoms Canada* releases real-time personalized recommendations and goals for self-management of GWG. We have also included sleep content with guidance related to the adoption of healthful sleep patterns, a known contributor to weight management.[139,140] All interaction with participants occurs through intervention features. The SmartTips feature, which drives the intervention, outlines clinically important information bullets. Other contents of this mHealth tool include: 1) Health page: the flagship features of the app (weekly GWG ranges according to the participant pregravid BMI, resting heart rate, hours of sleep, and steps) will be displayed in the health page; 2) Exercise database: includes stretching, warm-up and an extensive list of recommended, safe exercises (with video or photo guidance) for women during pregnancy. This page includes evidence-based information from the 2019 Canadian guideline for physical activity throughout pregnancy[83] as well. Also, a list of local physical activity resource centres/facilities (i.e., walking parks) will be displayed by the app; and 3) Dashboard: greeting the participants with a description of the baby's development characteristics for each gestational week. Figure 1 includes some features of the *SmartMoms Canada* app.

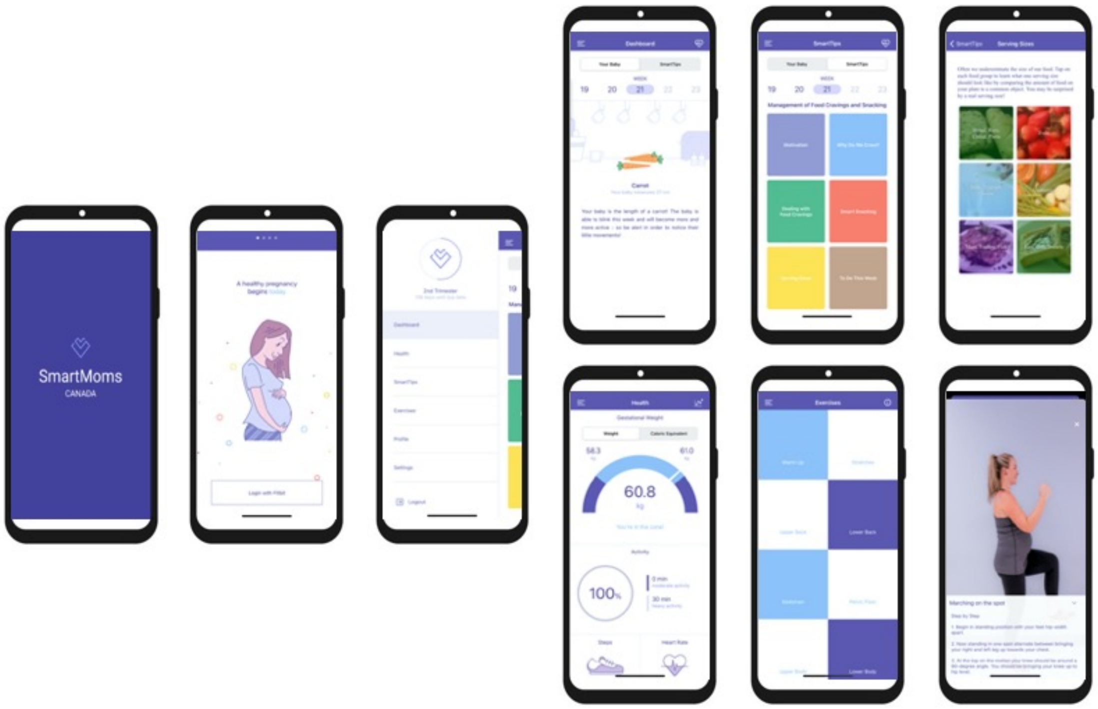

Figure 1. Screenshots showing some features from the *SmartMoms Canada* app

Participating women are provided with the *SmartMoms Canada* app to be installed on their mobile device, and the associated Wi-Fi enabled accessories during their first assessment. These accessories monitor body weight (Withings® Body+ Wi-Fi scale), and daily nutrition intake, physical activity, and sleep patterns (Fitbit® Charge 2 activity tracker). This intervention is divided in six main assessments, three during pregnancy (12-20, 24-28 and 36-40 gestational weeks) and three after giving birth (6 weeks, 6 and 12 months postpartum). In each of these time points, participants are asked to complete online questionnaires. Although some questionnaires may differ between assessments, participants are required to complete validated surveys regarding physical activity (Godin Leisure Time Exercise), sleep quality (PSQI), HRQoL, and depression (Edinburgh Pre/postnatal Depression Scale) at all six time points.

In the week following the completion of the online questionnaires, participants are asked to: 1) Wear and sleep with their Fitbit® tracker to gauge their physical activity and sleep patterns for seven consecutive days and 2) Access the Fitbit® app to record nutritional information (2 weekdays + 1 weekend day). Each participant's weight measurements are recorded by the Withings® Body+ scale. Participants will be required to collect their weight a minimum of once per week. The *SmartMoms Canada* participants' data have been collected on an ongoing basis since January 2021. For this thesis, data from the first two assessments (12-20 and 24-28 gestational weeks) regarding GWG, diet, physical activity, and sleep were collected to analyze if a higher usage of the *SmartMoms Canada* app is associated with improved outcomes when compared to a lower usage of this mHealth tool.

CHAPTER 3

PREAMBLE TO ARTICLE 1

The following article titled, “Eating Habits, Advice from Family/Friends, and Limited Personal Effort May Increase the Likelihood of Gaining Outside Gestational Weight Gain Recommendations” was published in the Maternal and Child Health Journal on September, 2020.

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Eating Habits, Advice from Family/Friends, and Limited Personal Effort May Increase the Likelihood of Gaining Outside Gestational Weight Gain Recommendations

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Abstract

Objectives The present study analyzed the association between (i) eating habits during pregnancy, (ii) advice from family or friends about gestational weight gain (GWG), and iii) personal effort to stay within weight gain limits, and meeting GWG recommendations.

Methods Participants included pregnant and postpartum women who completed the validated electronic maternal health survey (EMat). Sociodemographic, lifestyle variables, and body mass index were covariates used in the analyses.

Results Among all eligible women (1171), and a subset of women receiving a specific GWG target from HCP (365, 31.2%), participants who considered that their eating habits became less healthy, or could not evaluate if habits changed, had a higher likelihood of gaining above (adjusted odds ratio, aOR = 2.62; 95% CI 1.84; 3.73 for the total sample (TS); aOR = 4.79; CI 2.32;9.88 for the subset) GWG guidelines after adjusting for the covariates. Women who received advice from family or friends about how much weight they should gain while pregnant were more likely to experience GWG below (TS: aOR = 1.49; CI 1.02;2.17; subset: aOR = 1.95; CI 1.03;3.68) and above (TS: aOR = 1.42; CI 1.01;1.99; subset: aOR = 1.92; CI 1.06;3.48) guidelines, when compared to women who did not receive family/friends advice. Moreover, lower personal effort to stay within weight gain limits was associated with gaining below (TS: aOR = 1.77; CI 1.07;2.92; subset: aOR = 2.71; CI 1.30; 5.65) GWG guidelines.

Conclusions for Practice Women self-reporting less healthy eating habits than before pregnancy, receiving advice from family/friends about GWG, and lower personal effort to stay within guidelines, had an increased odds of weight gain discordant with recommendations.

Keywords Pregnancy · Weight gain · Behaviour · Feeding behaviour

Significance

What is already known: Despite receiving gestational weight gain (GWG) guidance from health care providers (HCP), most women were discordant with recommendations. Because sub-optimal GWG is associated with detrimental outcomes for women and children, it is important to investigate factors associated with failing to meet weight gain recommendations. What this study adds: Pregnant and postpartum women, self-reporting eating habits less healthy than before, receiving advice from family/friends about GWG, and self-perceived low personal effort to meeting GWG recommendations, increases the odds of weight gain discordant with guidelines. These findings highlight factors to consider by HCP when counselling women about GWG.

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Introduction

Gestational weight gain (GWG) is an expected outcome of pregnancy, although gaining too little or too much weight may negatively affect the health of both women and their children. Sub-optimal GWG is associated with preterm birth, small- or large- for- gestational- age babies, macrosomia, postpartum weight retention and gestational diabetes mellitus (Catalano et al. 2014; Ferraro et al. 2015; Goldstein et al. 2017; Zanotti et al. 2015). A meta-analysis including over 1 million pregnant women demonstrated that 47% exceeded the Institute of Medicine's (IOM 2009) GWG guidelines, whereas 23% gained below IOM recommendations (Goldstein et al. 2017).

Considering the maternal-fetal health risks associated with gaining above or below GWG guidelines, monitoring weight gain trajectory throughout pregnancy has become a public health priority. As a result, health care providers (HCP) should be routinely performing weight measurements (Weeks et al. 2018). When HCP offer counselling about GWG to their patients, the odds of women gaining within GWG guidelines significantly increase (Liu et al. 2016; Strychar et al. 2000). This guideline-concordant weight gain may be due to pregnancy being a 'teachable moment' when women, often in regular contact with HCP, are more likely to adhere to HCP recommendations (Phelan 2010). Although Liu et al. (2016) determined that HCP advice contributes to increased odds of weight gain within GWG guidelines, two-thirds of women in their sample gained outside guidelines despite receiving recommendations. These findings suggest that other factors might be influencing weight gain during pregnancy even when HCP offer guidance.

Besides physical activity, Plante et al. (2018) proposed a relationship model in which the two main factors interacting to explain GWG are psychosocial factors and dietary intake. Psychosocial factors such as social context and personal efforts/attitudes toward weight have been described as key predictors of GWG (Ockenden et al. 2016; Plante et al. 2018; McDonald et al. 2013; Richards et al. 2009). A systematic review of qualitative studies demonstrated that the social environment should be considered when providing advice for managing weight gain throughout pregnancy (Vanstone et al. 2017). Moreover, Hill et al. (2013) suggest that psychosocial factors (e.g., increased depressive symptoms, anxiety, and lower self-esteem) are linked to excessive GWG. These authors propose a conceptual model to track the relationships between maternal psychosocial factors (e.g., confidence and motivation to adopt healthy lifestyle behaviours) and actual behaviour changes, and to understand the pathway of factors related to GWG (Hill et al. 2013). Besides maternal psychosocial factors, engagement of family (e.g., parents) and friends in preventative health care behaviours is associated with higher levels of pregnant women participating in general health practices and using the health care system. However, the impact of GWG-related counselling from family/friends on guideline concordance is still lacking (Richards et al. 2009).

Negative attitudes (e.g., higher emotional instability) toward weight can also help explain inadequate GWG (McDonald et al. 2013). Negative attitudes related to weight control might be linked with a lack of motivation to adhere to the GWG recommendations (van der Wijden et al. 2014), which can result in a reduced personal effort to achieve guidelines. Recently, Weeks et al. (2020) showed that more than half of women did not make an effort to meet GWG recommendations. Furthermore, women with low self-efficacy and external locus of control (e.g., weight gain perception as beyond their control) were less likely to achieve guideline-concordant GWG (Halili et al. 2019).

More specifically, in terms of behaviours, diet has been considered one of the principal modifiable factors influencing GWG (Plante et al. 2018). A recent literature review indicated that changes in dietary behaviours throughout pregnancy, including high food restraint and cravings, increased the risk of exceeding GWG guidelines (Plante et al. 2018). In fact, healthier eating patterns (e.g., high vegetables and fruits intake) (Olson and Strawderman, 2003) or less healthy eating patterns (e.g., increased margarine, butter, cakes and snacks (Tielemans et al. 2015) can reduce and increase the risk of being outside GWG guidelines, respectively.

Based on the Social Cognitive Theory (SCT) (Bandura 2004), the psychosocial variables and behaviours described above might interact and will predict subsequent health outcomes, such as GWG. The SCT was the psychological theoretical framework used to develop the electronic maternal health survey (EMat) (Ockenden et al. 2016) to address women's knowledge and perceptions of the current GWG guidelines, and pregnancy-related health behaviours. The main theoretical framework of the present study is reciprocal determinism, which reflects (i) learned experiences, (ii) social context, and (iii) responses to information and advice. In combination, these three factors will produce a response to each question. Lifestyle health behaviours assessed by the EMat health survey include changes in dietary behaviours. Psychosocial aspects related to health behaviours are also captured in the instrument. For example, advice from family/friends related to GWG, and personal focused efforts to stay within the HCP's recommendations for GWG are considered in the survey (Ockenden et al. 2016). Multiple constructs are present in the SCT; however, the outcome expectations (i.e., can be influenced by the outcome or behaviours of others) were considered to analyze the impact of receiving advice from family or friends on GWG in the current study. Moreover, self-efficacy (i.e., one's perceptions of own control over behaviours) and locus of control (i.e., belief whether external [the environment] or internal [one's own personality, choices, thoughts] factors are controlling one's behaviour) were taken into consideration as indicators of personal effort to stay within weight gain limits during pregnancy. These constructs were highlighted and considered modifiable by previous health behaviour change studies (Bandura 2004; Redding et al. 2000).

As previous research suggests that HCP counselling can increase the likelihood of gaining within GWG guidelines, the aim of the current study was to identify potential changes in dietary behaviours and psychosocial factors that may be contributing to sub-optimal GWG. We hypothesized that eating behaviours less healthy than before pregnancy, receiving GWG advice from friends/family, and self-perceived low personal effort to stay within weight gain limits would be associated with not meeting target recommendations.

Methods

Participants and Data Collection

The study was approved by the relevant Research Ethics Boards (REB#09/03E; 14/183X), and the procedures were performed following the Declaration of Helsinki and its later amendments. Participants consented electronically to take part in the study before initiation of the EMat survey, administered from 2014 to 2018. The eligibility criteria used in the present study were: (1) age ≥ 18 years old; (2) being pregnant at the time of the survey or having given birth in the last five years; (3) English-speaking; (4) carrying a single fetus; (5) having reported pre-gravid and current weight for pregnant women and GWG for postpartum women. Women who gave birth to more than one child in the past five years were asked to report information related to their most recent pregnancy. Recruitment was performed by snowball sampling through social media such as Facebook® and Twitter® with secure links to the survey.

The self-administered EMat survey assesses knowledge, behaviours, and perceptions related to a variety of prenatal practices and was previously validated following rigorous procedures (Ockenden et al. 2016). Data were captured and stored using a secure data capture tool (REDCap™, Vanderbilt University, Nashville, TN, USA).

We used the closed-ended EMat survey question "Did your health care provider give you a specific weight gain amount or a weight gain range for your pregnancy?" and included women who answered "Yes" for this question in the subset analysis.

Pre-pregnancy weight and weight at the end of pregnancy were extracted from the EMat dataset to calculate total GWG. Pre-pregnancy body mass index (BMI) was obtained from the same survey to determine if women met guidelines or not (IOM 2009). All participants were grouped as gained below, within (reference), and above IOM GWG guidelines (dependent variable). Figure 1 presents the flowchart of the participants included in the study analysis.

Variables of Interest

Independent variables included in the analyses were questions related to eating habits during pregnancy, receiving advice from family or friends about GWG, and personal focused efforts to stay within the HCP's recommendations for GWG. The question: "Have you changed your eating habits at all (either for better or worse) during this pregnancy?" was used to evaluate changes in eating habits. Answers were initially analyzed with three categories (1- 'my eating habits became healthier'; 2- 'my eating habits stayed the same'; 3- 'became less healthy or could not evaluate if they changed') using the third category ('became less healthy or could not evaluate if they changed') as the reference. However, the adjusted odds ratio (aOR) for predicting women outside of GWG guideline was very similar for women who reported 'eating habits became healthier' (aOR: 0.345; 95% confidence interval, CI 0.163–0.731) and 'eating habits stayed the same' (aOR: 0.311; CI 0.152–0.634). Consequently, the answers were grouped as 'my eating habits

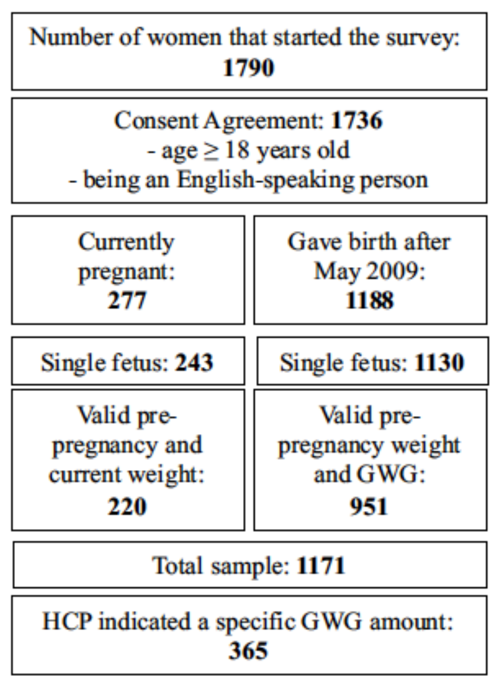

Fig. 1 Flowchart of the participants included in the study analysis

became healthier / my eating habits stayed the same' and 'became less healthy or could not evaluate if they changed'. Information about family/friends advice was obtained by the question: "Did you receive advice from your family or friends about how much weight to gain while pregnant?". Answers were grouped as 'yes' or 'no'. Furthermore, personal focused efforts were assessed by the question: "Did you make a focused effort to stay within the weight gain limits given to you by your health care provider?". Answers were classified as 'always / most of the time / sometimes' and 'rarely / never'.

Covariates

Analyses were adjusted for the following variables: Sociodemographic characteristics (age group, marital status, level of education, employment status, and approximate annual household income); other lifestyle variables (physical activity, smoking, and alcohol habits); and BMI.

Statistical Analysis

Descriptive statistics for categorical variables were used to describe the characteristics of the total and subset sample. Logistic regression analyses were conducted to explore associations between the three independent variables and meeting GWG guidelines (i.e., below, within, and above GWG guidelines) for all women (total sample, TS), and for only women who received any GWG guidance from HCP (subset). Relevant covariates were adjusted in the analyses, and aOR and CI were presented. Analyses were performed in SPSS program, version 13.0.

Results

Among all eligible women ($n = 1171$), only 365 (31.2%) women reported receiving advice from their HCP and were included in the subset analysis. Sociodemographic characteristics and behavioural aspects of the participants for the total and subset sample are described in Table 1.

Women who considered that their eating habits became less healthy or could not evaluate if the eating habits changed, were more likely to gain above GWG recommendations when compared to women who considered their eating habits to have stayed the same or became more healthy, regardless of sociodemographic characteristics, lifestyle, and BMI (aOR = 2.62; CI 1.84; 3.73 for the TS; aOR = 4.79; CI 2.32; 9.88 for the subset; Table 2). Receiving advice from family or friends about GWG was associated with gaining below (TS: aOR = 1.49; CI 1.02; 2.17; subset: aOR = 1.95; CI 1.03; 3.68) and above (TS: aOR = 1.42; CI 1.01; 1.99; subset: aOR = 1.92; CI 1.06; 3.48) guidelines, when compared to women who did not receive family/friends advice (Table 2). Moreover, self-perceived low personal effort to stay within weight gain limits was more likely to result in weight gain below (TS: aOR = 1.77; CI 1.07; 2.92; subset: aOR = 2.71; CI 1.30; 5.65) GWG guidelines (Table 2).

Conclusions for Practice

The present analysis focuses on eating habit changes, advice from family/friends, and personal effort to follow GWG guidelines on meeting recommendations. Our analysis is unique in that it also examined a subset of women who received HCP guidance on GWG. Results suggest that participants who self-reported a reduction in healthy eating habits, who received advice from family/friends about weight gain during pregnancy, and declared putting forth a lower personal effort to stay within weight gain limits, had a greater likelihood of being discordant with recommendations. Sociodemographic characteristics, lifestyle conditions (i.e., smoking, alcohol consumption, and frequency of physical activity), and BMI were not confounders for these associations.

Factors such as higher socioeconomic status, being nulliparous, older age, history of dieting, low physical activity, and having an overweight or obese BMI increases the odds of receiving any form of HCP guidance regarding GWG (Weeks et al. 2018). However, other studies highlighted that even after receiving GWG guidance from HCP during pregnancy, the prevalence of women gaining weight outside the recommended guidelines was still high (Liu et al. 2016; McDonald et al. 2011). It is unlikely that HCP advice alone attributes to appropriate GWG, and thus alternative factors may be contributing. According to our findings, eating behaviours (i.e., reporting less healthy eating habits/not being able to evaluate if habits have changed), friends/family advising about GWG, and self-perceived low effort to stay within weight gain limits appeared as risk factors that may potentially be contributing to gaining below or above GWG guidelines, despite receiving counselling from HCP.

Eating behaviours, diet quality, and dietary patterns are relevant factors related to GWG (Plante et al. 2018). Several studies reported that previous eating behaviours such as (i) cravings, (ii) high restraint, and (iii) marginal food insecurity, can increase the risk of being outside the GWG recommendations (Allison et al. 2012; Conway et al. 1999; Laraia et al. 2013; Orloff et al. 2016). In a sample where only 25.5% of pregnant women gained adequate weight, Laraia et al. (2013) showed that women previously exposed to marginal food insecurity and who scored high on dietary restraint experienced higher GWG. Our findings suggest that eating behaviours should be a key topic to be discussed in

Table 1 Characteristics of pregnant and postpartum women

Characteristics	Total sample *n* (%)	Women who received a specific GWG amount from HCP *n* (%)
Total	1171 (100.0)	365 (100.0)
BMI (kg/m^2)		
< 18.5	35 (3.0)	11 (3.0)
18.5–24.9	778 (66.4)	249 (68.2)
25–29.9	288 (24.6)	84 (23.0)
≥ 30	70 (6.0)	21 (5.8)
Age (y)		
18–29	191 (16.3)	60 (16.4)
30–39	861 (73.5)	265 (72.6)
≥ 40	119 (10.2)	40 (11.0)
Marital status		
Common law or married	1115 (95.5)	341 (93.4)
Divorced or separated/ Single/ Others	53 (4.5)	24 (6.6)
Missing	3	
Level of education		
Graduate or bachelor degree/ Non-University or trade certification	1071 (91.6)	337 (92.6)
Some post-secondary education/high school/ GED	98 (8.4)	27 (7.4)
Missing	2	1
Employment status		
Employed/self-employed/student	1039 (88.9)	325 (89.5)
Current unemployed/other	130 (11.1)	38 (10.5)
Prefer not to answer or missing	2	2
Annual household income		
CA $60,000–150,000+	971 (87.6)	292 (85.9)
Less than CA $60,000	138 (12.4)	48 (14.1)
Prefer not to answer or missing	62	25
Consumed alcoholic beverages during pregnancy		
Never	848 (76.3)	274 (79.4)
Yes (different frequencies)	264 (23.7)	71 (20.6)
Missing	59	20
Smoked cigarettes during Pregnancy		
Never	1077 (97.2)	334 (97.7)
Yes (different frequencies)	31 (2.8)	8 (2.3)
Prefer not to answer or missing	63	23
Weekly frequency of PA		
3–5	586 (56.8)	179 (55.6)
0–2	446 (43.2)	143 (44.4)
Prefer not to answer or missing	139	43
Eating habits changed during pregnancy		
Became more healthy/stayed the same	818 (74.6)	257 (76.0)
Became less healthy/ I don't know	278 (25.4)	81 (24.0)
Missing	75	27
Received advice from family or friends about how much weight to gain while pregnant		
No	661 (66.0)	167 (52.0)
Yes	341 (34.0)	154 (48.0)
Missing	169	44

Table 1 (continued)

Characteristics	Total sample	Women who received a specific GWG amount from HCP
	n (%)	*n* (%)
Effort to stay within weight gain limits		
Always/most of the time/sometimes	457 (72.0)	283 (78.0)
Rarely/never	178 (28.0)	80 (22.0)
Missing	536	2
GWG		
Below	274 (23.4)	90 (24.7)
Within	476 (40.6)	149 (40.8)
Above	421 (36.0)	126 (34.5)

GWG gestational weight gain; *HCP* health care providers; *BMI* body mass index; *GED* general educational development; *CA$* Canadian dollars; *PA* physical activity

Table 2 The relationship between changes in eating habits, having received advice from family or friends about GWG, and personal effort to stay within weight gain limits during pregnancy, and meeting GWG guidelines

Variables	GWG guidelines	
	Below	Above
Eating habits changed during pregnancy		
Total sample	aOR (95% CI)	aOR (95% CI)
More healthy/the same	1.00	1.00
Less healthy/ I don't know	1.10 (0.72; 1.68)	2.62 (1.84; 3.73)*
Women who received a specific GWG amount from HCP	aOR (95% CI)	aOR (95% CI)
More healthy/the same	1.00	1.00
Less healthy/ I don't know	1.47 (0.63; 3.41)	4.79 (2.32; 9.88)*
Received advice from family or friends about how much weight to gain while pregnant		
Total sample	aOR (95% CI)	aOR (95% CI)
No	1.00	1.00
Yes	1.49 (1.02; 2.17)*	1.42 (1.01; 1.99)*
Women who received a specific GWG amount from HCP	aOR (95% CI)	aOR (95% CI)
No	1.00	1.00
Yes	1.95 (1.03; 3.68)*	1.92 (1.06; 3.48)*
Effort to stay within weight gain limits		
Total Sample	aOR (95% CI)	aOR (95% CI)
Always/most of the time/sometimes	1.00	1.00
Rarely/never	1.77 (1.07; 2.92)*	1.45 (0.92; 2.29)
Women who received a specific GWG amount from HCP	aOR (95% CI)	aOR (95% CI)
Always/most of the time/sometimes	1.00	1.00
Rarely/never	2.71 (1.30; 5.65)*	1.89 (0.93; 3.82)

aOR: Odds ratio obtained through a logistic regression model adjusted by age, marital status, level of education, employment status, household income, alcohol consumption, smoking status, frequency of physical activity, and pre-pregnant BMI indicated

CI confidence interval, *GWG* gestational weight gain; *HCP* health care providers

*$p<0.05$

prenatal appointments. Pregnant women are often aware of the importance of healthy lifestyle habits and are motivated to improve health behaviours, but effective communication seems to be lacking (Nikolopoulos et al. 2017). For instance, Nikolopoulos et al. (2017) performed a qualitative study looking at HCP communication with pregnant women. The authors reported that poor HCP communication when discussing eating behaviours might lead to feelings of guilt and judgement. For example, a woman reported that the obstetrician told her "you can't be eating junk food" instead of having a sensitive discussion about diet behaviours, which resulted in negative emotions (e.g., guilty, blame, irresponsibility). Combined with our results, it seems that while HCP and pregnant women are generally aware of the importance of healthy behaviours during pregnancy, such as healthy eating, more sensitive and patient-centred communication is required to address these issues.

In the present study, women who received any advice about how much weight to gain while pregnant from family/friends were more likely to be outside (below and above) of GWG guidelines, when compared to pregnant women who received advice only from their HCP after adjusting for sociodemographic, lifestyle, and BMI. Social, cultural, and the physical environment have been recognized as important factors associated with GWG (Davis et al., 2012). Pregnant women's social/cultural interactions (e.g., with their families and family's beliefs) may influence their own food beliefs (Guelfi et al. 2015). Although social support (i.e., assistance of family and friends) is generally associated with healthy outcomes, such as physical activity participation, engagement in preventive health care behaviours, and reduced smoking, alcohol and caffeine consumption (Tinius et al. 2020; Richards et al. 2009; Aaronson 1989), GWG-related guidance from family/friends may negatively impact weight gain during pregnancy. Certain social norms, such as *'eating for two'* during pregnancy, are commonly transferred from generation to generation (Carruth and Skinner 1991; Tovar et al. 2010), indicating that non-expert advice may be sabotaging a woman's efforts to be within recommendations. Research in a non-pregnant population showed that independent of self-awareness, health behaviours are strongly influenced by a mimicry model (Reid et al. 2019). For example, exposure to family or friends engaged in an unhealthy lifestyle is associated with increased personal consumption of alcohol and unhealthy foods. As a result, HCP should focus on the promotion of healthy behaviours among pregnant women and their networks (i.e., family and friends) (Aaronson 1989). Women look for advice from family or friends about GWG, as these individuals are present in their routine interactions far more frequently than any HCP, and thus speaking to the quality of guidance provided may be necessary.

While one would expect lack of personal effort to be associated with GWG outside guidelines, our findings indicate that limited personal effort was associated only with gaining weight below guidelines after adjustment for covariates, when compared to GWG within guidelines. In line with our findings, McDonald et al. (2013) have shown that a lack of self-efficacy in achieving a healthy weight, and towards controlling food intake, increases the likelihood of gaining below versus within GWG guidelines. Weeks et al. (2020) found that 56% of pregnant and postpartum women reported that they did not make an effort to stay within the guideline recommendations. Although studies addressing the association between personal efforts and motivation to manage GWG are lacking, being motivated to achieve the guideline goals (IOM 2009) is related to a healthy pregnancy attitude (Althuizen et al. 2006). Positive attitudes including a well-balanced diet and wanting to achieve GWG recommendations were associated with less weight gain during late pregnancy (van der Wijden et al. 2014). However, the authors highlighted that further studies should explore the influence of pregnancy attitudes on GWG (van der Wijden et al. 2014).

Albeit a convenience sample, one strength of our study is the large sample size included to analyze the main associations. Moreover, the analysis was adjusted for several potential covariates (i.e., sociodemographic, lifestyle, and BMI) and the data were obtained through a valid and reliable instrument (Ockenden et al. 2016). Similar to most subjective measurements, a limitation of the current questionnaire-based study is the self-reported information about the gestational period (e.g., pre-pregnancy BMI, GWG), which is subject to memory bias (i.e., up to 5 years in the current analysis). However, pregnant and pre-pregnant data (e.g., pre-BMI, pregnancy-related characteristics and behaviours, and GWG) can be reliably recalled (Biro et al. 1999; McClure et al. 2011). Evidence suggests that pregnancy-related events recalled by women 32 years after delivery are highly correlated with documented pregnancy information such as pre-pregnancy height ($r=0.90$) and weight ($r=0.86$), obstetrics complications ($r=0.89$), and birthweight ($r=0.91$) (Tomeo et al. 1999). Another consideration is that the present study performed a subset analysis of women who received a specific weight gain target or range for their pregnancies from their HCP; however, as we are relying on a woman's account we cannot be sure of the exact advice provided. Finally, the cross-sectional design of the study does not permit the establishment of a causal association between the main factors evaluated and GWG outside guidelines.

The present study demonstrates that receiving advice from HCP is not sufficient to ensure GWG compliance and acknowledges that other factors need to be considered. Changing eating habits to those habits described as less healthy, receiving advice from family/friends about GWG, and lower personal effort to stay within weight gain limits during pregnancy increases the odds of weight gain discordant with recommendations despite receiving GWG advice from HCP. The associations observed for changes in eating habits, family/friends GWG advice, and personal effort were maintained after adjustment for covariates, such as sociodemographic characteristics, lifestyle variables, and BMI. In addition to HCP counselling, the development of patient-centred approaches focused on healthy lifestyle behaviours (e.g., mHealth and community-based interventions) during pregnancy may help promote gaining within GWG recommendations.

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Compliance with Ethical Standards

Conflict of interest All authors declare that they have no conflict of interest.

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CHAPTER 4

PREAMBLE TO ARTICLE 2

Given the findings from the EMat study illustrating that the implementation of mHealth interventions focused on healthy behaviours during pregnancy may promote adequate GWG, we wanted to examine whether establishing an avenue for evidence-based guidance and feedback would help pregnant women to achieve optimal GWG and healthy behaviours. The following article titled, “The short-term effect of a mHealth intervention on gestational weight gain and health behaviors: The SmartMoms Canada pilot study”, will be submitted to Physiology & Behavior in October, 2021.

The short-term effect of a mHealth intervention on gestational weight gain and health behaviors: The *SmartMoms Canada* pilot study

Abstract

Gestational weight gain (GWG) has been shown to impact several maternal-infant health outcomes. Since healthcare provider guidance on weight gain and healthy behaviors alone has failed to help women to meet guidelines during pregnancy, a practical adjunctive approach is to deliver evidence-based information through mobile interventions. The present study aimed to assess the short-term effect of the *SmartMoms Canada* app to promote adequate GWG and healthy behaviors. Twenty-nine pregnant women were recruited in this app-based intervention trial to test whether a higher app usage ($\geq$ 3.8 min·week^{-1}) between 12-20 gestational weeks and 24-28 gestational weeks improved GWG, diet, physical activity, and sleep, compared to women with a lower app usage (< 3.8 min·week^{-1}). Two-way mixed ANOVA for repeated measures was used to estimate the effect of the app usage and time, as well as their interaction on weight gain and healthy behaviors. The likelihood ratio was used to examine the association between app usage categorization and GWG classification. Cramer's V statistic was used to estimate the effect size for interpretation of the association. Pregnant women using the *SmartMoms Canada* app more frequently had a higher moderate-to-vigorous physical activity (MVPA) daily average when compared with women with a lower usage (mean difference: 17.84 min/day, 95% CI: 2.44; 33.25). A moderate effect size was found for the association between app categorization and rate of GWG, representing a greater adherence to the GWG guidelines in women in the higher app usage group *vs.* the lower app usage group (28.6% *vs.* 15.4%; Cramer's V = 0.212). Considering other physical activity, diet, and sleep variables, no app categorization effect was observed. A short-term higher usage of *SmartMoms Canada* app has a positive effect on objectively-measured MVPA.

1 Introduction

Women regularly seek information on gestational weight gain (GWG) and healthy behaviors during pregnancy, but the guidance from healthcare providers has rarely been helpful.[1-5] At the same time, there is a lack of evidence-based tools to support health professionals with providing advice to women on positive behaviors.[6-8] Given the importance of long-term metabolic programming that begins *in utero*,[9] pregnancy represents an ideal period for preventing chronic diseases.[10] Pregnancy has been referred to as a stress test for life.[11]

Unfortunately, when the fetus is exposed to a suboptimal intrauterine environment these perturbations can impact current and future maternal-infant outcomes, and heighten downstream risk for chronic disease.[12,13] Therefore, intervening during pregnancy with healthy behavior change and supporting healthcare providers with disseminating this information may have a multi-generational effect for chronic disease prevention.

GWG has been shown to affect maternal and infant health outcomes.[14] Although gaining weight during pregnancy is expected, suboptimal GWG (defined by the United States Institute of Medicine [IOM] recommendations)[14] has been linked to several complications such as hypertensive disorders of pregnancy,[15] large- and small-for-gestational-age neonates[16] as well as been implicated in the inter-generational cycle of obesity.[14,17-21] Adequate energy balance is one of the main factors contributing to GWG in line with recommendations.[22] Either under- or overnutrition and physical activity may impact intrauterine metabolic pathways and increase the risk of developing diseases beyond the neonatal period.[23,24] Evidence from diet and physical activity interventions during pregnancy consistently illustrate improved maternal and infant health outcomes.[25]

Another pivotal factor impacting energy balance during pregnancy is physical activity. Being active during pregnancy is a healthy behavior and a safe practice for women without contraindications.[26,27] Positive pregnancy outcomes, including weight management, reduced risk of gestational diabetes, and improved psychological health have been associated with regular physical activity.[27-30] Evidence from diet and physical activity interventions during pregnancy consistently illustrate improved maternal and infant health outcomes.[25] Nonetheless, other maternal health behaviors, such as sleep patterns, still require further investigation during pregnancy.[31] Although a previous study has identified similarities in sleep habits (e.g., total sleep duration, REM, deep, and light sleep) of pregnant *versus* non-pregnant women,[32] there are differences to be considered.[33] For instance, total sleep time decreases from the first trimester to the third trimester, and sleep duration is shorter during gestation compared with the pre-pregnancy time.[34,35] Impaired sleep has been associated with preeclampsia and hypertensive disorders of pregnancy, gestational diabetes, caesarean section, preterm birth, large-for-gestational-age neonates, and stillbirth.[36]

Weight management and adoption of healthful behaviors (i.e., adequate diet, physical activity, and sleep habits) in early pregnancy are key intervention targets for the prevention of potential adverse maternal and child health outcomes. Recent research has shown that exceeding GWG guidelines in the second trimester is strongly related to excessive weight gain in the end of pregnancy (sensitivity > 90% for all body mass index [BMI] categories).[37] The adoption of behavioral strategies, such as action planning and goal setting in the early stages of pregnancy, may help women to overcome common barriers to engaging in healthy prenatal behaviors.[38]

Evidence shows that lifestyle interventions during pregnancy are consistent in reducing GWG.[25] However, previous programs have primarily been delivered in-person, and this is both costly and time-consuming for patients and healthcare providers. Moreover, financial limitations and geographical barriers have prevented many women from achieving adequate GWG and healthful behaviors.[41] As such, a cost-effective alternative to overcoming limitations of standard in-person interventions is the adoption of mobile health (mHealth) tools.[42,43] mHealth is defined as a health practice supported by mobile devices, and can range from the simple use of websites to more complex functionalities like applications (apps).[44]

Women from different economic levels and ethnicities report being willing to use dietary and exercise information during pregnancy from digital sources to assist them with engaging in a healthy lifestyle.[45] Pregnant women are consistently looking for timely information and envisage that mHealth tools will help health professionals accessing their data.[46] The mHealth features to optimize weight gain during pregnancy have been considered valuable by users[47] and may decrease GWG in participants with pre-pregnancy overweight and obesity.[48] One novel mHealth tool is the *SmartMoms Canada* app. This app delivers real-time prenatal weight management and healthy behavioral support. Canada is one of the world leaders in online engagement and smartphone penetration, with 99% of the adult population having access to wireless networks and 90% owning a mobile phone.[49,50] About 96% of women in their childbearing years indicate being interested in receiving guidance on prenatal care through their phone.[51] An American version of the *SmartMoms* app has been shown to be efficacious in decreasing the proportion of women above the GWG recommendations by ~30% compared to standard prenatal care alone.[52] The Canadian version incorporates a greater breadth of features and includes an expanded dashboard, sleep tips, stress management advice, exercise ideas, and other unique Canada-centric features. According to a systematic review, multicomponent app interventions seem more effective than apps focused on a single behavior.[42] The *SmartMoms Canada* app has undergone focus group testing with pregnant and early postpartum women for co-design and refinement of the app, with improvements being described elsewhere.[53] The present study aims to assess the short-term effect of the *SmartMoms Canada* app usage patterns in helping women achieve adequate GWG and adhere to healthful behaviors related to nutrition, physical activity, and sleep in the early stages of pregnancy. We hypothesized that higher usage of the app will positively impact the adoption of nutritional, physical activity, and sleep behaviors compared to a lower usage of the app.

2 Methods

2.1 Study Design

The *SmartMoms Canada* program is a multi-centre, non-randomized, interventional study. The present study is part of the usability beta testing phase of the app. Among our goals during this phase is the determination of app usage, server management and functionality, and how this implicates on the outcomes of interest. The current analysis is focused on the impact of app usage on GWG and healthy behaviors. Ethics approvals from the University of Ottawa Research Ethics Board (H09194795-REG4795) and University of Manitoba Research Ethics Board (HS23407-H2019:448) were granted, and all research procedures followed the Declaration of Helsinki and its later amendments. All data were collected online at 12-20 (first assessment) and 24-28 gestational weeks (second assessment); we established these assessment periods to standardize procedures and compare different pregnancy time points.

2.2 Participants and Recruitment

Pregnant women, aged 18-40 years with pre-pregnancy BMI between 18.5 and 39.9 kg/m^2, were recruited across Canada and included in the study if they were between 12-20 weeks of gestation. Recruitment was carried out through online/internet sources including social media platforms (i.e., twitter, Instagram and Facebook sites). Eligibility criteria also included: 1)

Carrying a singleton fetus; 2) with Wi-Fi access; 3) Not consuming alcohol, tobacco or other drugs; 4) No contraindications to exercise during pregnancy or medical condition that may impact maternal and fetal weight; and 5) Able to communicate in English or French. Participants enrolled in the study between February and April 2021.

2.3 Sample Size Determination

Despite the paucity of studies assessing the short-term effects of mHealth interventions during pregnancy on health behavioral outcomes, we identified and modeled our sample size based on the study performed by Choi *et al*.[54] who recruited pregnant women at 10-20 weeks and assessed the changes in steps per day 5-9 weeks later after using a physical activity-centred app during pregnancy. Considering the similarity in the recruitment window, study duration, and one of the outcomes of interest, we determined the minimal sample size required for the present study based on their data. Accounting for an estimated change of 1092.1 ± 1925.3 steps per day during this period, considering an 80% power and 5% error, the minimal sample size required for the present study was n = 27 participants. We could not incorporate app usage from the literature into the sample size calculation due to the lack of available studies on this topic. We estimated the minimal sample size for the within (pre *vs.* post) and between (higher usage *vs.* lower usage) analyses accounting for an effect size F = 0.3 (moderate to large), 80% power, and 5% error. Considering these parameters, and using GPower 3.1.4 (Dusseldorf, Germany), the minimal required sample size is estimated to be n = 12/group (higher and lower app usage).

2.4 SmartMoms Canada Intervention

Women were provided with complimentary access to the *SmartMoms Canada* app, and the associated Wi-Fi/Bluetooth enabled accessories after consenting to participate in the study. These accessories were used to monitor participants' diet, physical activity, and sleep patterns (Fitbit® Charge 2 activity tracker) and bodyweight (Withings Health Mate® Body+ scale). The *SmartMoms Canada* app provides a continuous feedback loop that enables pregnant women to monitor daily nutrition, physical activity, sleep, and weekly GWG in their own environment.

This real-time feedback is possible because the *SmartMoms Canada* app is asynchronous with the diet, physical activity, sleep and weight data stored by the Fitbit® and Withings® apps. All interaction occurs through intervention features such as the 'SmartTips', 'Health', and 'Exercise' pages. The 'SmartTips' content page, which drives the intervention, includes clinically important information about evidence-based healthful behaviors during pregnancy. Time spent by the participants using the *SmartMoms Canada* app is automatically tracked by the Firebase® platform that is only accessible by the *SmartMoms Canada* research team, as well as data regarding their diet, physical activity and sleep that is tracked by the server. Firebase® is an application created by Google® that provides tools for tracking analytics. Figure 1 outlines the data management process/flow for this study.

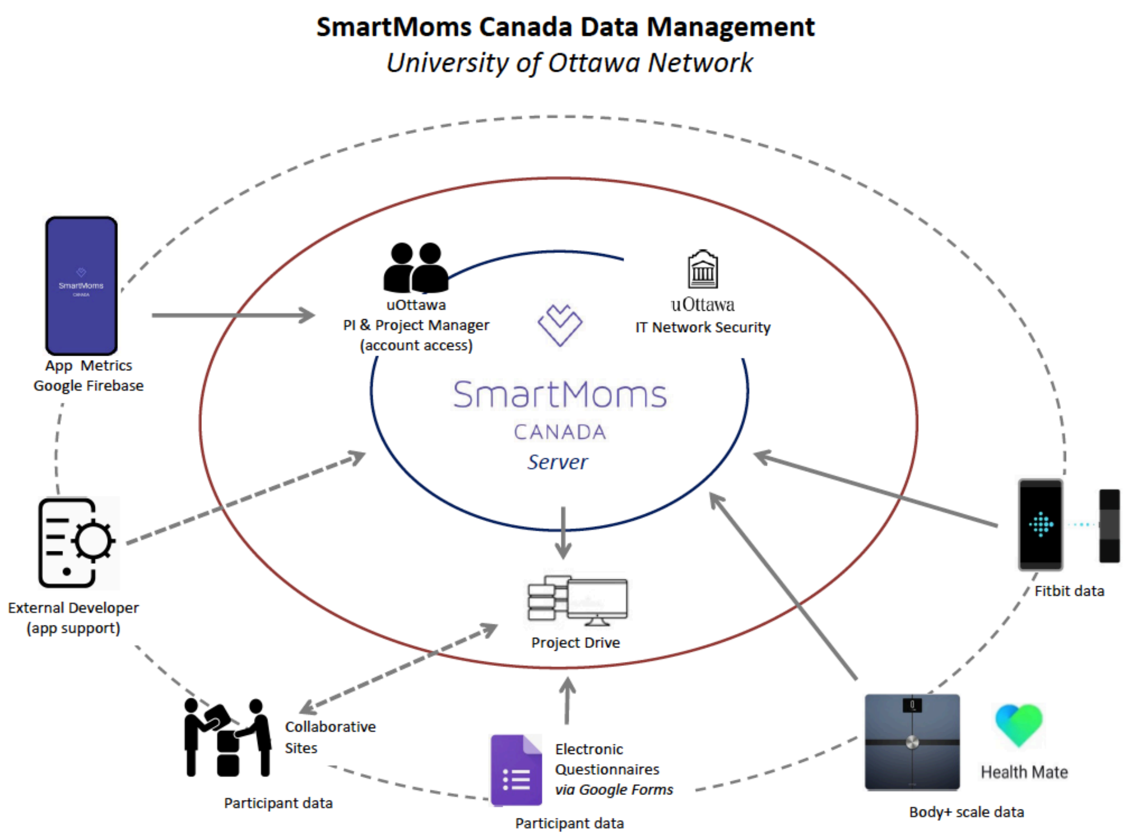

Figure 1. *SmartMoms Canada* – Data Management diagram. Solid arrows describe participants data that is automatically tracked by the server or project driver. Dashed arrows describe support from the external developers of the app and researchers from the collaborative sites.

2.5 Assessments

Participants completed two assessments which occurred 7.1 ± 2.0 weeks apart. Assessment 1 occurred between 12-20 gestational weeks. After providing informed consent, participants received instructions to install the *SmartMoms Canada* app and associated Wi-Fi accessories on their mobile device. After the installation of the three apps required for the study, participants started their first 'assessment week' (i.e., seven consecutive days). During this week, they were asked to wear the wrist-worn Fitbit® for seven consecutive days and nights to track their physical activity and sleep patterns. For the diet, participants were also advised to record their nutritional information using the Fitbit® app for a minimum of three days (two weekdays and one weekend day) within the seven-day period. Participant weight measurements were recorded using the Body+ scale. Participants were instructed to weigh using the provided scale at least once per week for tracking purposes until the study completion. Participants also completed online forms (i.e., Google® forms) to obtain sociodemographic information, exercise (Godin Leisure Time Exercise, GLTE), and sleep (Pittsburgh Sleep Quality Index, PSQI) data. Participants were encouraged to use the app and devices provided as much as possible during the study course.

The second seven-day assessment period occurred between 24-28 gestational weeks. Participants received an email reminding them to use the app and devices for seven consecutive days as they did during the first assessment. Data regarding their diet, physical activity, and sleep patterns were again collected through the *SmartMoms Canada* server, and the GLTE and PSQI questionnaires were also completed a second time.

2.6 Variables

GWG. Gestational weight gain (in kg) between the two assessment weeks was calculated by subtracting the first weight measurement of the participant that was captured during the corresponding assessment week from their self-reported pre-pregnancy weight. Women were classified into GWG groups (i.e., below, within, and above) based on the weekly ranges provided in the IOM recommendations,[14] according to their pre-pregnancy BMI calculated using self-reported values of weight and height.

Diet. Participants were instructed to use the Fitbit® app to log their food during the assessment weeks to obtain information regarding their total caloric intake (in kcal), with consumption of fat, carbohydrates, fibre, and protein (in grams) also captured. Only data from participants that completed at least three food logs (in two-week days and one weekend day) were included in the analysis. Nutritional data were considered invalid if the average of total caloric intake reported was 32% below or above the energy expenditure expected for each participant.[55] The calculation of the energy expenditure expected for each participant considered participants pre-pregnancy weight and BMI, GWG, and gestational age.[56]

Physical activity. Total daily steps and minutes spent in each physical activity intensity (i.e., vigorous, moderate, light) per day were computed by Fitbit® and captured by the *SmartMoms Canada* server. Daily steps less than 1000 counts were treated as invalid measurements, possibly due to Fitbit® being worn for only a small portion of the day, and excluded from the analysis. The minimum of 1000 counts was considered based on previous studies utilizing pedometers and Fitbits®.[54,57,58] All participants had their physical activity data captured for at least 4 days during the assessment week. Self-reported leisure-time physical activity was also assessed through the GLTE questionnaire at assessments 1 and 2. For the GLTE score calculation, self-reported weekly frequencies of strenuous, moderate, and mild activities are multiplied by nine, five, and three, respectively; the resulted values correspond to MET value categories of the activities listed.[59] The final score presented in this study is exclusively based on the sum of the strenuous and moderate activities as recommended by the validation study.[59,60]

Sleep. Fitbit® computed the duration (in minutes) of each sleep stage, including REM, deep, and light sleep, and uploaded in the server. The sum of these three sleep stages was used to calculate total sleep duration. All sleep variables were converted into hours for the results presentation. Previous literature suggests that daily sleep time <2 or >12 hours should be excluded in an attempt to remove potential erroneous observations;[61] however, sleep data from all participants were within this range. Sleep quality information was also assessed through the PSQI at assessments 1 and 2. In brief, the PSQI is a validated instrument used to measure the quality and patterns of sleep.[62] The PSQI total score was adopted in our analysis, with higher scores indicating poorer sleep quality (range 0-21).

***SmartMoms Canada* app usage**. The total number of weeks that each participant was exposed to the app between the first and second assessment weeks, as well as the time spent in the app was captured by the Firebase® platform. Firebase is an application created by Google that provides tools for tracking analytics. Based on the total number of weeks and total duration of the app usage (in minutes), we calculated the total duration per week (minutes/week) that the participants used the *SmartMoms Canada* app. Based on the median value of app usage per week, we determined the higher (≥ median) and lower app usage (< median) groups.

The flowchart below (see Figure 2) summarizes all the procedures adopted in the present study.

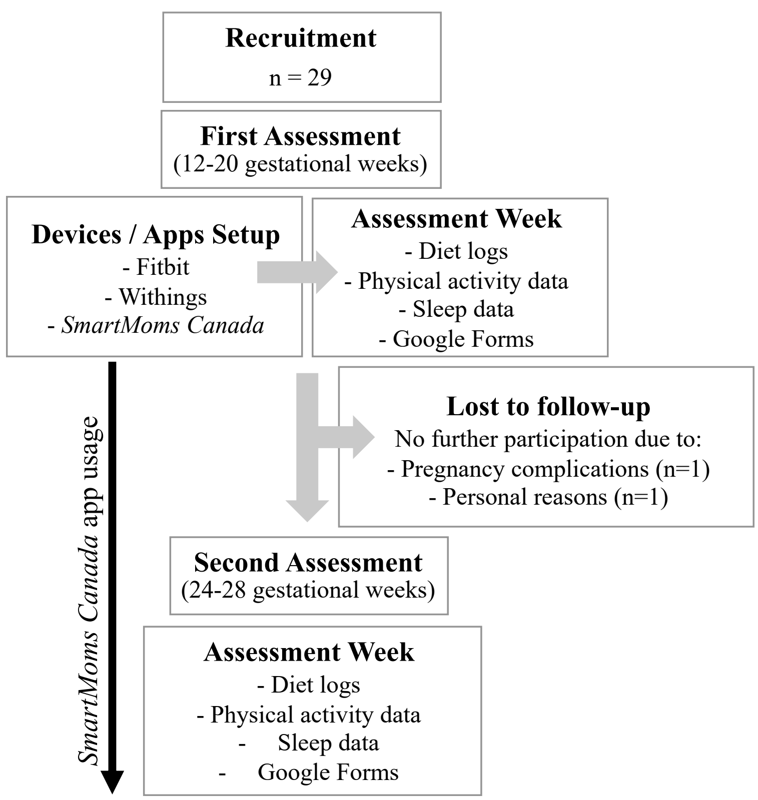

Figure 2. Flowchart of the *SmartMoms Canada* study

2.7 Statistical Analysis

Descriptive data are presented as mean ± standard deviation (SD). Two-way mixed ANOVA for repeated measures was used to estimate the effect of the app usage categorization (higher *vs.* lower usage) and time (assessment 1 *vs.* 2) and their interaction on GWG, diet, physical activity, and sleep patterns. Adjustments for multiple comparisons were performed according to the Bonferroni correction, and the magnitude of potential observed differences was computed as effect sizes (eta squared, η^2). The values of 0.0099, 0.0588, and 0.1379 were used as cut-offs for small, moderate, and large effect sizes, respectively.[63] The likelihood ratio was used to check the association between app usage categorization and GWG classification at assessment 2. Cramer's V statistic was used to estimate the effect size for interpretation of the association.[64] The values of 0.07, 0.21, and 0.35 were used as cut-offs for small, moderate, and large effect sizes (for degrees of freedom = 2), respectively.[64] The significance level was set at $p < 0.05$. All statistical analyses were completed using SPSS software, version 23.0 (IBM Corp, Armonk, NY).

3 Results

From the 29 pregnant women recruited in urban areas for the present study, a total of n = 27 were included in the analysis. Participants (n = 2) declared pregnancy complications and personal reasons for withdrawing from the study. Participant anthropometrics, demographics and app usage are described in Table 1. Diet, physical activity and sleep patterns were not different between the first and second assessments, nor did they differ between the higher and lower usage groups at the first assessment.

Table 1. Characteristics of the participants (n = 27)

Variable	Mean ± SD or n [%]
SmartMoms Canada app usage	
Total use (min)	33.9 ± 27.0
Number of weeks (wk)	7.1 ± 2.0
Total use per week (min·wk^{-1})	4.6 ± 2.9

Age (in years)	31.6 ± 3.8
Pre-pregnancy weight (kg)	70.0 ± 13.7
Height (m)	1.66 ± 6.8
Pre-pregnancy BMI classification	
Normal weight	14 [51.9]
Overweight	11 [40.7]
Obese	2 [7.4]
Gestational age at assessment 1 (weeks)	18.7 ± 2.4
Gestational age at assessment 2 (weeks)	25.0 ± 1.0
GWG at assessment 1 (kg)	3.4 ± 2.9
GWG at assessment 2 (kg)	7.2 ± 3.5
Parity	
0	18 [66.7]
1	8 [29.6]
2	1 [3.7]
Ethnicity	
White	22 [81.5]
East or Southeast Asian	3 [11.1]
Black	1 [3.7]
Middle Eastern	1 [3.7]
Education	
High school	1 [3.7]
College	2 [7.4]
University	21 [77.8]
Post-graduate studies	3 [11.1]
Current Occupation	
Employed	23 [85.2]
Unemployed	1 [3.7]
Work from home	1 [3.7]
Other	2 [7.4]
Number of work hours per week	
< 20	1 [3.7]
20 – 40	13 [48.1]
41 – 60	10 [37.0]
> 60	2 [7.4]
Not-applicable	1 [3.7]
Household annual income (in CA$)	
30,000 – 59,999	1 [3.7]
60,000 – 89,999	1 [3.7]
90,000 – 119,999	8 [29.6]
120,000 – 149,999	6 [22.2]
≥ 150,000	9 [33.3]
Refuse to answer	2 [7.4]

SD: standard deviation; BMI: body mass index; GWG: gestational weight gain; min: min; wk: week

The total app usage per week was classified according to the median value (M = 3.8 $min{\cdot}wk^{-1}$) from which participants were divided into the higher ($\geq$ 3.8 $min{\cdot}wk^{-1}$, n = 14) and lower (< 3.8 $min{\cdot}wk^{-1}$, n = 13) usage groups (see Figure 3).

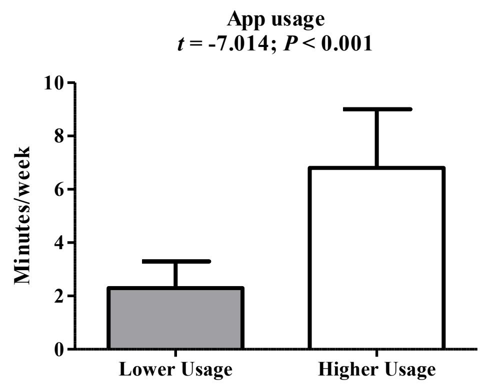

Figure 3. Total app usage per week in the higher and lower app usage groups

The GWG classification per usage group in the second assessment can be seen in the Figure 4. Although not statistically significant, we found a moderate effect size (i.e., Cramer's V = 0.212) for this association. A total of four (28.6%) women met the GWG guidelines in the higher usage group compared to two women (15.4%) in the lower usage group.

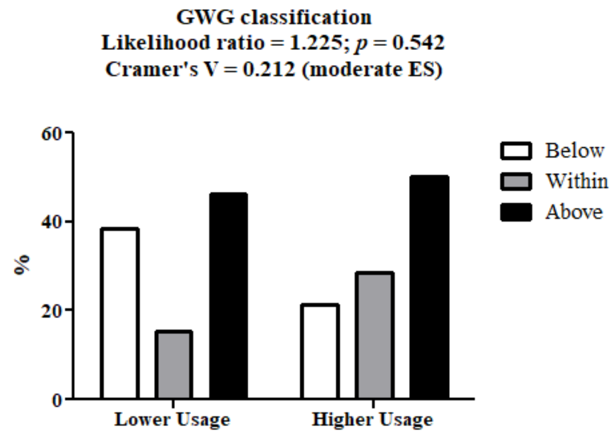

Figure 4. GWG classification at assessment 2 per app usage group

3.1 Diet Variables

Six participants from the higher usage group and seven from the lower one did not consistently complete the food logs during two-week days and one weekend day in one of the two assessment weeks or under reported their total caloric intake, and were not included in the diet variables analysis. A total of 14 participants were included in the diet analysis. For total caloric intake, two-way mixed ANOVA for repeated measures revealed no effect for app usage (F = 0.103, p = 0.753, η^2 = 0.009), time (F = 0.540, p = 0.477, η^2 = 0.043), and no interaction between app usage and time (F = 0.085, p = 0.776, η^2 = 0.007). Similar results were observed for the consumption of fat, carbohydrates, fibre, and protein, with no app usage effect (see Table 2).

Table 2. The effect of *SmartMoms Canada* app usage diet patterns at assessment 1 and 2

Diet variables	App usage (n)	Mean ± SD		
		Assessment 1 (12-20 weeks)	Assessment 2 (24-28 weeks)	Total
Total calories ($kcal\cdot d^{-1}$)	Higher (8)	2112.7 ± 285.5	2082.0 ± 245.9	2097.4 ± 357.4
	Lower (6)	2089.0 ± 154.7	2018.0 ± 403.4	2053.5 ± 357.0
	Total (14)	2102.6 ± 230.8	2054.5 ± 310.2	
Fat ($g\cdot d^{-1}$)	Higher (8)	81.6 ± 18.0	87.7 ± 15.7	84.6 ± 18.5
	Lower (6)	82.6 ± 15.3	74.8 ± 15.7	78.7 ± 18.4

	Total (14)	82.0 ± 16.3	82.2 ± 16.5	
	Higher (8)	248.5 ± 38.2	232.2 ± 24.3	240.3 ± 48.9
Carbohydrates ($g \cdot d^{-1}$)	Lower (6)	243.1 ± 34.8	248.9 ± 48.0	246.0 ± 48.8
	Total (14)	246.2 ± 35.5	239.3 ± 35.7	
	Higher (8)	22.0 ± 7.0	21.8 ± 6.6	21.9 ± 8.2
Fibre ($g \cdot d^{-1}$)	Lower (6)	22.4 ± 5.2	19.0 ± 5.5	20.7 ± 8.2
	Total (14)	22.1 ± 6.0	20.6 ± 6.1	
	Higher (8)	89.9 ± 17.2	93.9 ± 15.6	91.9 ± 15.9
Protein ($g \cdot d^{-1}$)	Lower (6)	83.0 ± 7.1	84.9 ± 15.5	84.0 ± 15.9
	Total (14)	87.0 ± 13.8	90.1 ± 15.7	

SD: standard deviation; kcal: kilocalories; g: grams; d: day

3.2 Physical Activity Patterns

For the daily total steps, two-way mixed ANOVA for repeated measures revealed no effect of app usage ($F = 0.207$ $p = 0.653$, $\eta^2 = 0.008$), time ($F = 1.422$, $p = 0.244$, $\eta^2 = 0.054$), and no interaction between app usage and time ($F = 0.252$, $p = 0.620$, $\eta^2 = 0.010$). Vigorous physical activity showed similar results, with no app usage effect ($F = 3.716$, $p = 0.065$, $\eta^2 = 0.129$), no time effect ($F = 0.671$, $p = 0.420$, $\eta^2 = 0.026$), and no interaction between these two factors ($F = 0.034$, $p = 0.855$, $\eta^2 = 0.001$). There was also no significant effect of app usage, time and no interaction between these two factors for light physical activity and for the GLTE score (see Table 3).

The analysis for moderate and moderate-to-vigorous physical activity (MVPA) demonstrated a significant app usage categorization effect ($F = 5.543$, $p = 0.027$, $\eta^2 = 0.181$; $F = 5.692$, $p = 0.025$, $\eta^2 = 0.185$). The multiple correction analysis based on the app usage showed that moderate (mean difference: 8.41, 95% confidence interval: 1.05; 15.77) and MVPA (mean difference: 17.84, 95% confidence interval: 2.44; 33.25) were greater for women more frequently using the *SmartMoms Canada* app compared with women with a lower usage. However, no time effect ($F = 0.364$, $p = 0.551$, $\eta^2 = 0.014$; $F = 0.018$, $p = 0.893$, $\eta^2 = 0.001$) nor interaction between the two factors was observed ($F = 0.486$, $p = 0.492$, $\eta^2 = 0.019$; $F = 0.077$, $p = 0.784$, $\eta^2 = 0.003$) (see Table 3).

Table 3. The effect of *SmartMoms Canada* app usage physical activity patterns at assessment 1 and 2

PA variables	App usage (n)	Mean ± SD		
		Assessment 1 (12-20 weeks)	Assessment 2 (24-28 weeks)	Total
Daily total steps	Higher (14)	7322 ± 2631	7605 ± 3098	7464 ± 3963
	Lower (13)	6625 ± 2389	7319 ± 3722	6972 ± 3962
	Total (27)	6986 ± 2494	7467 ± 3349	
Vigorous PA (min·d^{-1})	Higher (14)	22.1 ± 19.9	19.2 ± 14.3	20.7 ± 18.0
	Lower (13)	12.2 ± 9.0	10.3 ± 13.6	11.2 ± 18.0
	Total (27)	17.3 ± 16.1	14.9 ± 14.4	
Moderate PA (min·d^{-1})	Higher (14)	16.7 ± 12.8	20.4 ± 15.8	18.6 ± 13.1
	Lower (13)	10.3 ± 7.2	10.0 ± 9.3	10.2 ± 13.1*
	Total (27)	13.6 ± 10.8	15.4 ± 13.9	
MVPA (min·d^{-1})	Higher (14)	38.9 ± 28.7	39.6 ± 26.4	39.2 ± 27.5
	Lower (13)	22.5 ± 13.1	20.3 ± 22.2	21.4 ± 27.5*
	Total (27)	31.0 ± 23.7	30.3 ± 25.9	
Light PA (min·d^{-1})	Higher (14)	199 ± 58	202 ± 47	201 ± 108
	Lower (13)	249 ± 92	259 ± 108	254 ± 108
	Total (27)	223 ± 79	229 ± 86	
GLTE score	Higher (14)	19.7 ± 14.9	22.5 ± 15.8	21.1 ± 20.5
	Lower (13)	23.8 ± 17.2	23.4 ± 16.3	23.6 ± 20.5
	Total (27)	21.7 ± 15.9	22.9 ± 15.8	

SD: standard deviation; GLTE: Godin Leisure Time Exercise; PA: physical activity; MVPA: moderate-to-vigorous physical activity; min: minutes; d: day
*Different (p<0.05) from the higher app usage group.

3.3 Sleep Patterns

One participant from the higher app usage group did not consistently track her sleep patterns for 4+ days in one of the two assessment weeks and was not included in the sleep variables analysis. A total of 26 participants were included in the analysis of total sleep duration, awake time, REM, deep, and light sleep. For the total sleep duration, there was no effect of app usage ($F = 0.211$, $p = 0.650$, $\eta^2 = 0.009$), time effect ($F = 0.115$, $p = 0.737$, $\eta^2 = 0.005$), and no interaction between app usage category and time ($F = 0.435$, $p = 0.516$, $\eta^2 = 0.018$). Similar results were found for the sleep stages, including REM ($F = 0.679$, $p = 0.418$, $\eta^2 = 0.028$), deep

($F = 0.250$, $p = 0.622$, $\eta^2 = 0.010$), and light sleep ($F = 1.282$, $p = 0.269$, $\eta^2 = 0.051$) and for awake time and PSQI score (see Table 4).

Table 4. The effect of *SmartMoms Canada* app usage sleep patterns at assessment 1 and 2

Sleep variables	App usage (n)	Mean ± SD		
		Assessment 1 (12-20 weeks)	Assessment 2 (24-28 weeks)	Total
Total sleep duration ($h \cdot n^{-1}$)	Higher (14)	7.5 ± 0.9	7.4 ± 0.7	7.5 ± 1.0
	Lower (12)	7.3 ± 0.8	7.4 ± 0.7	7.3 ± 1.0
	Total (26)	7.4 ± 0.8	7.4 ± 0.7	
REM sleep ($h \cdot n^{-1}$)	Higher (14)	1.6 ± 0.2	1.6 ± 0.3	1.6 ± 0.3
	Lower (12)	1.6 ± 0.3	1.7 ± 0.3	1.7 ± 0.3
	Total (26)	1.6 ± 0.2	1.7 ± 0.3	
Deep sleep ($h \cdot n^{-1}$)	Higher (14)	1.1 ± 0.3	1.0 ± 0.4	1.1 ± 0.4
	Lower (12)	1.1 ± 0.3	1.2 ± 0.3	1.2 ± 0.4
	Total (26)	1.1 ± 0.3	1.1 ± 0.3	
Light sleep ($h \cdot n^{-1}$)	Higher (14)	4.8 ± 0.7	4.8 ± 0.7	4.8 ± 0.8
	Lower (12)	4.5 ± 0.6	4.5 ± 0.5	4.5 ± 0.8
	Total (26)	4.6 ± 0.7	4.7 ± 0.6	
Awake ($h \cdot n^{-1}$)	Higher (14)	1.1 ± 0.2	1.0 ± 0.2	1.1 ± 0.2
	Lower (12)	1.0 ± 0.1	1.1 ± 0.2	1.0 ± 0.2
	Total (26)	1.0 ± 0.2	1.0 ± 0.2	
PSQI score	Higher (14)	6.3 ± 3.0	5.8 ± 3.2	6.0 ± 3.7
	Lower (13)	5.5 ± 2.6	5.1 ± 2.6	5.3 ± 3.7
	Total (27)	5.9 ± 2.8	5.4 ± 2.9	

SD: standard deviation; PSQI: Pittsburgh Sleep Quality Index; h: hours; n: night

4 Discussion

The results of this data analysis found that, although not statistically significant, we observed a trend (i.e., moderate effect size) that more women in the higher app usage group were able to meet the GWG guidelines than the lower app usage group (28.6% *vs.* 15.4%). There was no time effect or interaction between app usage group and time; however, pregnant women with a higher usage of the *SmartMoms Canada* app had a greater MVPA daily average when compared with women with a lower usage (mean difference: 17.84 min/day, 95% CI: 2.44;

33.25). More frequent users of the *SmartMoms Canada* app had a higher daily average of moderate and MVPA when compared with women with a lower app usage. Considering other physical activity variables, diet and sleep patterns, no effect of app usage was observed.

The effectiveness of mHealth interventions to reduce excessive GWG is inconsistent in the literature. For instance, Dahl *et al.*[65] did not find a significant effect of a mobile app intervention on preventing guideline-discordant GWG. In contrast, Redman *et al.*[52] reported significant results and showed that fewer women exceeded GWG guidelines after exposure to their mHealth intervention (a previous iteration to the *SmartMoms* app used here). Different from the results presented in this study, previous findings[52,65] took into consideration the final GWG of the participants at late pregnancy. However, the high sensitivity of second-trimester excessive weight gain for total excessive GWG[37] may allow us to speculate that the moderate effect size found in our analysis is reflective of weight gain at the end of pregnancy. Considering that women gain most weight during mid-pregnancy,[66] it is possible to identify those at risk of exceeding GWG guidelines as early as the second trimester.[67]

A GWG dial showing participants their current bodyweight and weight gain ranges from the IOM guidelines is displayed in our 'Health' page. This feature of the *SmartMoms Canada* app together with other information present in the 'Health' page regarding physical activity levels achieved every day, steps, caloric intake, and sleep duration is expected to help participants managing their GWG and behaviors. This mHealth intervention is also driven by the content available at the 'Exercise' and 'SmartTips' pages. Participants have unlimited access to clinically important information about eating behaviors, stress management, physical activity, and sleep until the end of their pregnancy.

Although no intervention effect for improving GWG was observed by Dahl *et al.*[65], this group did report that the use of a mobile app may facilitate healthy behavior change through group-based goal setting and self-monitoring using a mobile app. Furthermore, a pilot study aiming to increase physical activity during pregnancy through a mHealth program found no statistically significant differences between intervention and control groups; however, participants showed interest in using an app to promote physical activity.[54] The *'2019 Canadian Guideline for Physical Activity throughout Pregnancy'* recommends that pregnant women should accumulate at least 150 min of moderate-intensity physical activity per week to prevent pregnancy complications and achieve optimal maternal and neonatal health outcomes.[27] The results of the present study demonstrating an increased average of moderate and MVPA in the group with higher app usage are promising and may have long-term benefits that need to be assessed in future research. Indeed, 35.7% of women in the higher usage group were considered 'very active' (≥300 $min \cdot w^{-1}$ of MVPA) and 28.6% were 'active' (≥150 - <300 $min \cdot w^{-1}$ of MVPA) at assessment 2 (total of 64.3%) *vs.* 7.7% of 'very active' and 38.5% of 'active' women in the lower usage group (total of 46.2%). Although these proportions were not statistically significant, the Cramer's V analysis suggested a moderate association between app usage and meeting physical activity guidelines (data not shown). In the study of Wang *et al*. with non-pregnant women, the establishment of physical activity goals (e.g., becoming more physically active), not the duration of use of physical activity apps, influenced the perceived effectiveness for increasing time spent exercising.[68] However, duration was measured in 'months exposed to the app'. App usage was linked with the perceived effectiveness of diversifying physical activities, sharing pictures or messages about exercise on social networks, and searching for physical activity online.[68]

The positive findings associated with the physical activity outcomes (i.e., moderate and MVPA) in the present study could be explained by the diverse content available at the 'Exercise' page of the *SmartMoms Canada* app. Our 'Exercise' page provides specific recommendations following the recently published physical activity guideline,[27] incorporates several images and examples of pregnancy-friendly exercises, and was updated to include feedback from participants that were part of the *SmartMoms Canada* focus group study.[53] Notifications within the app (e.g., alerts to remind participants to check specific information on the 'SmartTips' or 'Exercise' pages) that participants received periodically were added to help support their adherence to healthier behaviors. In fact, results of the *SmartMoms* focus group study highlighted that the exercise content of the app as one of the strengths perceived by pregnant and postpartum women.[53]

The literature on mHealth programs for pregnant women related to diet and sleep has been limited. Systematic review evidence on exclusively digital health interventions targeting diet, physical activity, and weight gain in pregnant women found 11 studies between 2012 and 2020.[69] Three app-based studies were identified,[52,54,65] and their main outcomes included

GWG[52,65] and physical activity[54]. A mHealth study published in 2021 observed an overall shift toward a healthier diet in participants using the app intervention compared to participants following standard prenatal care.[70] Comparisons between mHealth tools aiming to improve diet during pregnancy are challenging because nutritional interventions are complex with diverse foci and features. For example, the app proposed by Sandborg *et al*. that found an improvement in dietary behavior was designed to highlight the benefits of plant-based diets.[70] A research study examining non-pregnant population experiences of using an eating app found that frequent food logs were associated with lower bodyweight yet greater self-reported energy intake at 8 weeks of intervention.[71] The participant food logs in the present study represent a limitation associated with research using self-reported nutritional data. Although we only included values within the range of estimated energy expenditure for each participant in the analysis, the caloric intake values reported were still low.

A systematic review on interventions to improve sleep hygiene during pregnancy identified a lack of effective programs to alleviate poor sleep quality and insomnia.[72] To the best of our knowledge, no mHealth intervention to improve sleep patterns during pregnancy has been developed or evaluated. Although the impact of mind-body interventions on the sleep of pregnant women is unknown, mindfulness and yoga approaches can be delivered through a mobile app and have been effective in helping other populations.[73,74] Given the importance of sleep, more research on the effectiveness of mHealth interventions on sleep is necessary.

The strengths of this study include the objective measurement of physical activity, sleep, and bodyweight using a Fitbit® tracker and Withings Health Mate® scale. Our study also had the ability to collect information from participants outside the clinics (i.e., at home). Although mixed results have been published trying to validate existing consumer-wearable technology with research-grade monitors for agreement in physical activity levels,[75-77] Semanik *et al*.[78] found a strong correlation between specifically moderate physical activity measured using a Fitbit® and ActiGraph®. In addition, data from the present study regarding GWG, diet, physical activity, and sleep were collected during two pregnancy time points. There are only a few studies looking at the effect of app-based mHealth interventions on GWG, physical activity, and diet, and none evaluating the impact of these programs on sleep patterns.

Limitations of this study include the homogeneity of our population, as it is largely composed of educated, predominantly employed, urban-living, healthy pregnant women, mostly white, and with a high annual income, which limits external validity and generalizability. Other limitation was the non-standardization of total weeks of app use. The weekly time spent by the participants using the *SmartMoms Canada* app (4.6 ± 2.9 min·w^{-1}) between the first and second assessments may be considered an overall low app usage. However, the usage of individual app components including engagement with the Fitbit® and Withings® apps were not evaluated. Previous literature has shown a large inter-individual variation in the use of health apps (e.g., Walgreens, Fitbit, Nike+), with a range of 1-10 min per day.[79] The majority of studies evaluating the effect of app-based interventions during pregnancy have lacked a thorough evaluation, or consideration of participants' app usage. The only study analyzing app usage data considered app session count and used the median value to classify their participants as high and low app users.[80]

This analysis of the short-term effect of the *SmartMoms Canada* intervention appears promising when considering that women in the higher app usage group engaged in a greater daily level of MVPA when compared with women with a lower usage, suggesting potential to improve adherence to Canadian prenatal activity guidelines that specifically recommend this intensity level. Future analyses should focus on the long-term influence of this intervention on healthy behaviors and target a larger and more diverse population of pregnant women to increase the generalizability and overall statistical power. Data from the current study can guide future sample size calculations for larger mHealth intervention trials assessing different health behaviors in pregnancy.

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CHAPTER 5

5.1 DISCUSSION

5.1.1 EMat health survey

The first objective of this thesis was to analyze the association between i) eating habits during pregnancy, ii) advice from family or friends about GWG, and iii) personal effort to stay within weight gain limits, and meeting GWG recommendations. This was undertaken by examining cross-sectional data from the EMat health survey. The EMat is an online questionnaire, developed and validated by the Adamo Lab research group,[137] that aimed to evaluate factors that may impact GWG. From the 1,171 eligible women that completed the EMat survey and had their responses analyzed for the objective of this thesis, 365 participants reported receiving advice from their HCP about GWG recommendations and were included in the subset analysis. The main analysis of this study illustrated that eating behaviours (i.e., reporting less healthy eating habits/not being able to evaluate if habits have changed), friends/family advising about GWG, and making a lower effort to stay within weight gain limits appeared as risk factors that may potentially be contributing to being discordant with recommendations. Covariates such as sociodemographic characteristics, lifestyle, and BMI were not confounders for these associations.

Regardless of receiving HCP counselling about weight gain during pregnancy, our findings suggest that participants who self-reported a reduction in healthy eating habits, who received advice from family/friends about weight gain during pregnancy, and declared putting forth a lower personal effort to stay within weight gain limits, had a greater likelihood of gaining below or above GWG guidelines. These results are in accordance with previous work, in which a high number of pregnant women gained weight outside recommendations after receiving GWG counselling from their HCP.[117,141] Although specific characteristics (i.e., overweight or obese BMI, being pregnant for the first time, higher socioeconomic status and age, history of diet, and reporting low physical activity levels) may increase the likelihood of being advised regarding GWG recommendations,[115] HCP guidance alone seems to be not sufficient to guarantee adequate weight gain during pregnancy.

The association between poor eating behaviours and falling outside GWG guidelines is well established;[23,142-145] however, the lack of communication between HCP and pregnant women about healthy eating habits may prevent optimal weight gain during pregnancy.[146] Qualitative data have shown that women who experience poor communication with HCP about eating behaviours during pregnancy may develop feelings of guilt and judgement.[146] Pregnant women's food beliefs have also been associated with their cultural background.[147] The social and physical environment that women are exposed to will likely influence their behaviours and, consequently, GWG.[148] Common beliefs, such as 'eating for two' during pregnancy are frequently transferred between generations and can result in suboptimal GWG.[149] For this reason, HCP advice on GWG should take into account women's environment including their family and friends.

With regards to a woman's personal effort and meeting GWG guidelines, it is expected that positive attitudes (i.e., healthy diet and intention to achieve recommendations) are associated with optimal pregnancy outcomes.[150] Similar to the current literature,[31] our findings showed that a lack of personal effort increases the likelihood of gaining exclusively below GWG guidelines. Future research should better explore the association between personal self-efficacy and GWG.

Collectively this work demonstrated that receiving advice from HCP is likely not sufficient on its own in helping women to meet weight gain recommendations during pregnancy.

Other than improving the traditional in-person approaches, the implementation of new strategies such as mHealth and community-based interventions focused on optimal GWG and healthy behaviours may benefit women and their children.

5.1.2 *SmartMoms Canada* app

The second study of this thesis sought to assess the effectiveness of the *SmartMoms Canada* mHealth program in helping women achieve adequate GWG and adhere to healthful behaviours related to nutrition, physical activity, and sleep. Through the short-term implementation of this mHealth intervention, it was found that participants with a higher app usage had a greater daily average of moderate-to-vigorous physical activity in the second assessment when compared with women in the lower app usage group. A moderate effect size was observed when we compared rates of meeting GWG guidelines at assessment 2 (~24 gestational weeks) of women among the different app usage groups. The percentage of women within GWG recommendations was 28.6% in the higher usage group and 15.4% in the lower usage one. It is well-known that the majority of weight gain happens in the second-trimester[151] and the identification of women that may be already at risk of pregnancy complications due to gaining weight outside the recommendation is fundamental to an early and more effective intervention.[152] Given the high sensitivity of excessive weight gain between 19-28 gestational weeks for total GWG,[153] the findings of my second study regarding weight gain at assessment 2 are expected to be extrapolated to the total GWG (i.e., at the end of pregnancy).

As suggested in the discussion of the EMat study (first objective of this thesis), mHealth interventions may be a cost-effective solution to improving GWG and healthy behaviours during pregnancy. Considering that 99% of the Canadian population has access to wireless networks and 90% owns a mobile phone, the country continues to lead the world in online engagement.[120,121] A high percentage of women in their childbearing years use at least one smartphone app,[119] which suggests that this is a widely available route of delivery for health information. For instance, a systematic review on mHealth interventions for pregnant women identified only three app-based studies between 2012 and 2020.[129] These three app interventions have targeted GWG[130,132] and physical activity[131] only. A more recent app-based study from 2021 also looked at the effect of a lifestyle intervention on GWG, body fatness, dietary habits, physical activity, glycemia, and insulin resistance, and found a positive app effect in promoting healthy dietary behaviours.[154] Due to the limited number of mHealth interventions delivering information exclusively through apps, the findings regarding effectiveness of the use of evidence-based apps to improve GWG and healthy behaviours are inconsistent.

To the best of our knowledge, the *SmartMoms Canada* app program is the first one to address sleep during pregnancy. Moreover, the only previous study that considered rates of app usage during pregnancy evaluated app session count and not duration of usage.[155] The *SmartMoms Canada* app has shown a positive intervention effect if we consider that women with a higher app usage presented greater moderate-to-vigorous physical activity at the second assessment when compared with women in the lower usage group. According to the *'2019 Canadian Guideline for Physical Activity throughout Pregnancy'*, the practice of at least 150 min of moderate-to-vigorous physical activity per week is associated with the prevention of pregnancy complications.[83] The *SmartMoms Canada* app intervention is delivered through a diverse number of features, and one feature of particular relevance to my findings is the 'Exercise' page that has been evaluated in a focus group study and was updated based on pregnant and postpartum women feedback.[44] The exercise content was perceived as one of the strengths of the app and could be a factor contributing to our findings associated with improved physical activity.

Future studies should focus on the long-term effects of mHealth interventions on GWG management and healthy behaviours during pregnancy and take into consideration participants usage duration. Strategies to increase app usage may expand the effect of these interventions on other healthy behaviours. The results from this second thesis objective will assist future mHealth trials focused on diet, physical activity, and sleep behaviours.

5.2 LIMITATIONS

The limitations of the EMat and *SmartMoms Canada* studies are outlined in detail in the published and submitted manuscripts above (Chapter 3 and 4). For instance, there are specific limitations that have set the parameters of both studies presented in this thesis and are worthy of discussion. With respect to the characteristics of the EMat survey respondents and *SmartMoms Canada* participants, it is important to recognize that our sample is quite homogeneous and may not be fully representative of the Canadian pregnant population. Participants involved in both studies were predominantly educated, white, and with a high annual income. Future research should aim to recruit a more diverse population, so external validity and generalizability of the results will be possible.

5.3 FUTURE DIRECTIONS

Considering the association between eating habits, family/friends GWG advice, and personal effort with gaining weight outside guidelines that was found in the EMat study, alternative approaches that target these avenues should be considered to promote a healthy

GWG. The adoption of mHealth tools represents an innovative solution to common barriers of the traditional prenatal health care. For example, the use of 'smart' technologies such as the ones provided in the *SmartMoms Canada* study to track individual behaviours have become more attractive as mobile devices became ubiquitous. However, the literature on app-based interventions mediated by these technologies to promote healthy behaviours and adequate GWG is limited.

The *SmartMoms Canada* study presented in this thesis is an attempt at providing participants with a pregnancy-specific app designed to promote appropriate GWG and healthy behaviours. Evidence-based content was available in the diverse features of the app such as the 'SmartTips', 'Health', and 'Exercise' pages to be accessed by the participants at any time. Nonetheless, women engaged in the intervention were not asked to change their usual routines recommended by the HCP. Participants were generally advised to use the *SmartMoms Canada* app and the associated devices as much as possible during the study period without accesses and duration of usage being prescribed by the researchers.

In the context of future studies, there are five main recommendations based on the lessons learned in the EMat and *SmartMoms Canada* studies. The first recommendation is to confirm if the short-term results found in the *SmartMoms Canada* study will be carried over into long-term effects (e.g., at late pregnancy) of this mHealth intervention.

Second, we suggest that the effect sizes presented in the *SmartMoms Canada* study should be used in future research as they will permit more robust sample size calculations for the study outcomes (i.e., GWG and healthy behaviours). For instance, the present data will help our research team in preparing for a more substantial phase of *SmartMoms Canada* platform testing (i.e., implementation trial). The derived effects sizes can also inform the calculation of a cost savings analysis (e.g., reduced costs for patients, prenatal clinics, Canadian health system).

Third, in terms of future study populations, specific cultural and linguistic norms should be considered for future research to recruit a more diverse sample. The current version of the *SmartMoms Canada* app is a starting point that can be easily adapted for multiple languages, for different chronic conditions (e.g., targeting gestational diabetes or hypertensive patients), cultural variations, and extended into the postpartum period.

Fourth, future versions of the *SmartMoms Canada* app and other mHealth programs should take into account participants' feedback in order to increase their adherence to the intervention. Adherence is a common challenge in lifestyle intervention trials; however, we expect that the personalization, convenience, and flexibility offered by the app-based interventions will help increase participants engagement.

Lastly, based on the *SmartMoms Canada* app usage, the next version of this tool and other app-based interventions should consider adding specific tasks and goals to be completed by the participants. Specific to our *SmartMoms Canada* app, we could encourage regular app usage, with the inclusion of a specific exercise schedule. Other than exercise examples, participants would also have access to which activities they could complete at every gestational week. A merged platform for participants to engage with other group members may also benefit increasing app usage through social interactions. Group-based tasks could be created to enhance participant engagement.

5.4 CONCLUSION

Combined, the EMat and *SmartMoms Canada* studies have contributed to identify and target potential factors associated with discordant GWG and healthy behaviours. Understanding additional contributors of weight gain outside recommendations will help inform the development of interventions aimed at improving maternal and infant health outcomes. Factors such as eating behaviours, social context, and personal attitude highlighted in the EMat study have an important role on gaining weight within guidelines. Regardless of HCP guidance about GWG, women are likely influenced by their physical and social environment. These findings from the EMat study emphasize the utmost importance of alternative interventions to improve GWG management such as the *SmartMoms Canada* program. This app-based mHealth intervention is one of the first to focus on GWG along with healthy behaviours including diet, physical activity, and sleep during pregnancy. Overall, the short-term effects of the *SmartMoms Canada* app demonstrate promise in app-based interventions for GWG and physical activity behaviours.

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APPENDICES

Appendix 1. Additional Manuscripts and Projects

Along with my dissertation work, I have been actively involved with a national research project that is exploring sex-disparities in musculoskeletal injuries in the Canadian Armed Forces. My main role in this project was assisting in the development of an online survey that was responded by more than 2,000 military members. I have also led the analysis of nutritional and sleep data from this survey. Through this project, I have gained experience managing large datasets, complex statistical analyses, ethical approval processes and working with a diverse group of researchers and key stakeholders.

I have also contributed as first co-author on the manuscript entitled: *Does prepregnancy weight change have an effect on subsequent pregnancy health outcomes? A systematic review and meta-analysis*. This manuscript was recently accepted for publication in Obesity Reviews. In the last two years I have been part of 8 publications, 3 grant applications, and delivered 2 oral presentations. Please see below a list specifying these contributions and the manuscript that I am first co-author attached.

<u>Published Academic Papers</u>

1. Nagpal TS, **Souza SCS**, da Silva DF, Adamo KB. Taking a patient-oriented approach in exercise interventions for pregnant women: a commentary. Canadian Journal of Public Health. 2021 Jun;112(3):498-501.
2. Nagpal TS, Salas XR, Vallis M, Piccinini-Vallis H, Adamo KB, Alberga AS, Bell RC, da Silva DF, Davenport MH, Gaudet L, Rodriguez AC, Liu RH, Myre M, Nerenberg K, Nutter S, Russell-Mayhew S, **Souza SCS**, Vilhan C. Coming Soon: An Internalized

Weight Bias Assessment Scale for Use During Pregnancy. Obesity (Silver Spring, Md.). 2021 May;29(5):788-9.

3. da Silva DF, Mohammad S, Nagpal TS, **Souza SCS**, Colley RC, Adamo KB. How Many Valid Days Are Necessary to Assess Physical Activity Data From Accelerometry During Pregnancy? Journal of Physical Activity and Health. 2021 Feb 16;18(3):337-44.

4. Nagpal TS**, Souza SCS**, da Silva DF, Ferraro ZM, Sharma AM, Adamo KB. Widespread misconceptions about pregnancy for women living with obesity. Canadian Family Physician. 2021 Feb 1;67(2):85-7.

5. Nagpal TS, Bhattacharjee J, da Silva DF, **Souza SCS**, Mohammad S, Puranda JL, Abu-Dieh A, Cook J, Adamo KB. Physical activity may be an adjuvant treatment option for substance use disorders during pregnancy: A scoping review. Birth Defects Research. 2021 Feb 1;113(3):265-75.

6. Nagpal TS, Goldfield GS, da Silva DF, **Souza SCS**, Burhunduli P, Liu RH, Naylor PJ, Adamo KB. The effects of intervening with physical activity in the early years (ages 3–5) on health-related quality of life: a secondary analysis of the Activity Begins in Childhood (ABC) trial. Quality of Life Research. 2021 Jan;30(1):221-7.

7. Everest C, Nagpal TS, **Souza SCS**, Da Silva DF, Gaudet L, Mohammad S, Bhattacharjee J, Adamo KB. The Effect of Maternal Physical Activity and Gestational Weight Gain on Placental Efficiency. Medicine and Science in Sports and Exercise. 2020 Sep 25.

8. Nagpal TS, Everest C, **Souza SCS**, da Silva DF, Mohammad S, Bhattacharjee J, Adamo KB. Does "Sitting" Stand Alone? A Brief Report Evaluating the Effects of Prenatal Sedentary Time on Maternal and Newborn Anthropometric Outcomes. Journal of Physical Activity and Health. 2020 Aug 17;1(aop):1-5.

Research Funding Awards

1. Canadian Institutes of Health Research (CIHR) – Project Grant (2021 Spring Competition); Role: Collaborator – MSc student; Project title: SmartMoms Canada: An evaluation of a mobile app intervention to support a healthy pregnancy
2. SSHRC Partnership Grant (2020 Fall Competition); Role: Collaborator – MSc student; Project title: Understanding internalized weight bias during pregnancy
3. Department of National Defence (DND), Innovation for Defence Excellence and Security (IDEaS) (2019); Role: Collaborator – MSc student; Project title: A multi-stage approach to addressing sex-disparities in musculoskeletal injuries in military members

Conference Oral Presentations

1. Discovering new factors associated with gaining outside gestational weight gain recommendations and the translation of the 5As of Healthy Pregnancy Weight Gain. 7th Canadian Obesity Summit, Online (May 2021). On-Demand Plenary Presentation.
2. Eating habits and advice from family/friends increase the likelihood of gaining outside gestational weight gain recommendations. Canadian National Perinatal Research Meet (CNPRM), Banff – Canada (Feb 2020). Oral.

Title: Does prepregnancy weight change have an effect on subsequent pregnancy health outcomes? A systematic review and meta-analysis

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Keywords: Pregnancy, Weight, Body Mass Index, Perinatal, Preconception, Inter-pregnancy

Running Title: Prepregnancy weight change

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Conflicts of Interest: None to declare

Abstract:

International guidelines recommend women with an overweight or obese body mass index (BMI) aim to reduce their body weight prior to conception to reduce the risk of adverse perinatal outcomes. Recent systematic reviews have demonstrated that interpregnancy weight gain increases women's risk of developing adverse pregnancy outcomes in their subsequent pregnancy. Interpregnancy weight change studies exclude nulliparous women. This systematic review and meta-analysis was conducted following MOOSE guidelines and summarises the evidence of the impact of preconception and interpregnancy weight change on perinatal outcomes for women regardless of parity. Sixty studies met the inclusion criteria for this review and reported 34 different outcomes. We identified a significantly increased risk of gestational diabetes (OR 1.88, 95% CI 1.66, 2.14, I^2=87.8%), hypertensive disorders (OR 1.46 95% CI 1.12, 1.91, I^2=94.9%), preeclampsia (OR 1.92 95% CI 1.55, 2.37, I^2=93.6%), and large-for-gestational-age (OR 1.36, 95% CI 1.25, 1.49, I^2=92.2%) with preconception and interpregnancy weight gain. Interpregnancy weight loss only was significantly associated with increased risk for small-for-gestational-age (OR 1.29 95% CI 1.11, 1.50, I^2=89.9%) and preterm birth (OR 1.06 95% CI 1.00, 1.13, I^2=22.4%). Our findings illustrate the need for effective preconception and interpregnancy weight management support to improve pregnancy outcomes in subsequent pregnancies.

Abbreviations:
BMI – Body mass index; GDM – Gestational diabetes mellitus; GWG – Gestational weight gain
LGA – Large-for-gestational-age; MOOSE – Meta-analysis of observational studies; OR – Odds ratio; CI – Confidence intervals; SGA – Small-for-gestational-age; VBAC – Vaginal birth after caesarean

Introduction:

The positive association between maternal preconception body mass index (BMI) and adverse perinatal outcomes is well established.[1-3] Women who have obesity are at risk for pregnancy complications, including gestational diabetes (GDM), hypertensive disorders of pregnancy such as preeclampsia, and excessive gestational weight gain (GWG).[1,4] Pregnancy weight management guidelines suggest that women with an overweight or obese BMI (≥25.0 kg/m^2) should aim to reduce their body weight prior to conception to have a BMI within the recommended range (18.5-24.9 kg/m^2).[5-7] As the prevalence of maternal obesity increases,[8] more women of reproductive age may be attempting weight loss before conception as recommended by prenatal healthcare providers to reduce the risk for complications. Although there is evidence to show that preconception weight loss can improve fertility outcomes,[9] there is a paucity of knowledge on the effect of preconception weight change (loss or gain) on the development of subsequent perinatal complications.

Interpregnancy weight change (i.e., the weight gain or loss between two pregnancies) is a form of preconception weight change for parous women. Recently, three systematic reviews were completed evaluating the effect of interpregnancy weight change on perinatal outcomes in subsequent pregnancies.[10-12] Consistently, authors of these reviews reported that interpregnancy weight gain was associated with a higher risk for large-for-gestational-age (LGA) newborns and GDM in the second pregnancy, whereas interpregnancy weight loss decreased the risk for LGA newborns.[10-12] Furthermore, compared to women who maintained their prepregnancy BMI across pregnancies, those who gained weight between pregnancies were at greater risk of complications.[10-12] Authors concluded that both interpregnancy weight gain and maternal BMI are predictive factors for perinatal complications in subsequent pregnancies.[10-12]

The existing reviews which focus on interpregnancy weight change, by their nature, exclude primiparous women. Given the increasing prevalence of obesity among women of reproductive age and guideline recommendations to lose weight before pregnancy, women may have been attempting to lose weight in advance of their first pregnancy as well as between pregnancies.[8,13-15] It is estimated that approximately 42-44% of the adult general population attempt weight loss annually. Women are twice as likely as men to report weight loss or weight management efforts.[16] Therefore, in addition to interpregnancy weight change, first-time mothers may also experience preconception weight loss or gain, which may influence the development of perinatal complications. This systematic review aimed to explore the impact of weight change experienced before any pregnancy (i.e., first or subsequent pregnancy) on perinatal outcomes. This review extends the work performed by others that assessed interpregnancy weight change only.[10-12] Our goal is to provide information on the impact of weight change on perinatal outcomes, including prenatal and birth outcomes, for all women regardless of parity.

Methods:

Search Strategy:

This systematic review and meta-analysis was conducted in accordance with the recommendations for meta-analysis of observational studies in epidemiology (MOOSE)[17] and the protocol was registered on PROSPERO (CRD42019156949). The following databases were searched on October 23rd 2019, and updated on August 27th 2020: MEDLINE, Cochrane Reviews, Embase, and Scopus using keywords and MeSH headings for the terms preconception, weight change, and pregnancy (Table S1). Searches were limited to human studies, and no date or language restrictions were applied. In line with MOOSE guidelines, systematic reviews of observational studies require supplementary searches in addition to databases to comprehensively search for all relevant published data.[17] Therefore, two reviewers (RHL and SD) hand searched the reference lists of all related systematic reviews and included studies, and completed citation searches for all studies that met the inclusion criteria using Google Scholar Citations (Tables S2 and S3). If studies were identified through citation and reference list searches, they were subject to further reference list and citation searches and this process was repeated until no new studies were identified. If required, authors of included studies were contacted for additional data needed for the meta-analysis (Table S4).

Inclusion Criteria:

Inclusion criteria were peer-reviewed observational studies (cohort, case-control, or cross-sectional designs) with retrospective or prospective design, reporting the association between the exposure variable (preconception or interpregnancy weight change) and outcome variable (perinatal outcome). For the purpose of this review, data reported as preconception relates to weight change before any pregnancy for women of any parity that is not directly related to any previous pregnancies, whereas data for interpregnancy weight change refers specifically to weight change between two pregnancies. Weight change included weight loss or gain, and could be reported in any units (e.g., kg, BMI) and any perinatal health outcomes (e.g., GDM, GWG, preterm delivery, maternal mental health) were included.

Data Extraction:

Duplicate citations of the same study were excluded using the deduplication feature on Endnote software,[18] and remaining citations were transferred to Covidence[19] for screening. Titles and abstracts were initially screened to identify studies which potentially met the inclusion criteria, followed by a full text assessment against the inclusion criteria by two independent reviewers (TSN; SCSS). Studies which met the inclusion criteria but reported data from the same cohort were included if they reported different outcomes, otherwise duplicate data were excluded (Table S5). If studies reported duplicate data on the same outcome, we selected the study that reported the largest sample size and longest recruitment period for inclusion. Exclusions are reported in Table S6.

Standardized data extraction tables were developed for this review and included the following items: exposure, exposure reference group, exposure category, sample size for comparisons, perinatal outcome, measures of association, adjustments made to analyses. The following study characteristics were also extracted: study period, data source/registry, country of study, total sample size, inclusion and exclusion criteria, study objectives, definition of preconception or interpregnancy weight change, maternal age and BMI. Quality assessments were completed using the Newcastle-Ottawa scale for cohort and case-control studies (Tables S7 and S8).[20] The Newcastle-Ottawa scale assesses information and selection bias, and confounding variables. Data extraction and quality assessments were completed by two independent researchers for each included study (TSN; SCSS; TN; RHL).

Analysis:

Studies were pooled in a meta-analysis to estimate the odds-ratio (OR) and a 95% confidence interval (CI) when there were at least two studies reporting the same outcome. Meta-analysis of weight gain and weight loss were carried out separately. Sub-group meta-analysis was carried out, where possible, to compare the pooled effect sizes and heterogeneity for different time points of data collection (i.e., interpregnancy or preconception) and for different measures of weight change. The weight measurement subgroups included BMI change or "other measures" of weight change (e.g. kg, pounds, percent change), and were further stratified where possible based on whether or not there was an upper limit to the weight change. For example, if studies specified a range with an upper limit this was considered a defined upper limit (e.g., 1-2 BMI units change), whereasrange indicating greater than a specific value with no upper limit, was considered as no defined upper limit (e.g., >2 BMI units change). Supplementary meta-analyses were carried out to explore the combined association between weight change and maternal BMI. I^2 values of 25%, 50%, and 75% were used to indicate low, moderate and high levels of heterogeneity.[21] Sources of heterogeneity were initially explored through subgroup meta-analysis, and when high levels of heterogeneity remained meta-regression was carried out. Variables identified *a-priori* to be included in meta-regression for each outcome were related to study design (e.g. sample size, prospective or retrospective, adjustments made in the analysis), population (e.g. country of study, time period of study), outcome definition and quality. Publication bias was investigated using Egger's test and funnel plots. Sensitivity analysis was performed for each meta-analysis (including the overall pooled estimates and subgroup meta-analyses) to explore the effect of any individual results on the pooled effect size. Additionally, if there were three or more subgroups then sensitivity analysis was carried out excluding each subgroup to explore the potential implications of pooling different time periods and measures of weight change. All analysis was conducted in Stata v16.[22] If meta-analysis was not possible, studies were synthesized narratively in accordance with Popay et al.[23] guidance on the conduct of narrative synthesis in systematic reviews. Data were tabulated, transformed if possible where required (e.g. calculation of ORs using frequency data reported in the papers). Data were grouped into thematic categories, and the associations between preconception or interpregnancy weight change and perinatal outcomes was described including the estimate of effect size and variance.

Results:

Study Selection and Characteristics:

Database searches identified 3,149 studies for screening following deduplication, and supplementary searches identified a further 4,651 studies to be screened; of which 60 met the inclusion criteria and reported unique data (Fig S1). The included studies reported both preconception weight change (n=12) and interpregnancy weight change (n=48), and the following outcomes: GDM (n=22), any hypertensive disorder (n=19), preeclampsia (n=7), preterm birth (n=14), LGA (n=16), SGA (n=13), cesarean delivery (n=13), stillbirth and neonatal mortality (n=6), vaginal birth after caesarean (VBAC) (n=4), postnatal hemorrhage (n=2), Apgar scores (n=2), birthweight z-scores (n=2), any congenital malformation (n=2), and single studies for spina, bifida, gastroschisis, conotruncal birth heart defects, cleft lip, GWG, placental weight, neonatal intensive care unit admission, 3rd/4th degree tear, episiotomy, shoulder dystocia, hypoglycemia, birth trauma, respiratory distress, infant anthropometrics, meconium aspiration, neonatal seizures, pregnancy loss, induced labour, instrumental delivery, and maternal morbidity. Studies were published between 1999 and 2020, with sample sizes ranging from 72 to 526,435. The studies were carried out in the US (n=36), Australia and Sweden (n=6 each), England, France, Ireland and Scotland (n=2 each), Belgium, Canada, Denmark and Norway (n=1 each) (Table S9).

The quality of included studies ranged between 3-8 stars for cohort studies (n=38 high quality, n=12 medium quality, n=0 low quality), and 4-8 stars for case control studies (n=7 high quality, n=3 medium quality, n=0 low quality) (Table S10 and S11). Cohort studies had the highest scores on the selection of the non-exposed cohort being the same community as exposed cohort (question 2), the representativeness of the exposed cohort being either truly or somewhat representative to average maternal population in the community (question 1), and having an adequate follow-up period for the outcome of interest (question 6). The lowest scoring criteria related to the ascertainment of exposure (question 3) which generally used self-reported measures. The highest scores in case control studies were for the use of the same method of ascertainment for cases and controls (question 7), and same non-response rate for both groups (question 8). The lowest scoring criteria were for the definition of controls having no description of the source (question 4) and, similar to the cohort studies, the ascertainment of exposure was mostly self-reported (question 6).

Meta-analysis was possible for GDM, hypertensive disorders of pregnancy, preeclampsia, LGA, small-for-gestational-age (SGA), caesarean delivery, vaginal birth after cesarean (VBAC), stillbirth, preterm delivery, low Apgar score, and postpartum hemorrhage. It was possible to stratify meta-analysis for most outcomes by preconception and interpregnancy weight gain; however, for weight loss there were only preconception data available for LGA and the remaining meta-analyses are limited to the interpregnancy period. The additional data that could not be pooled into meta-analysis were grouped into three themes relating to neonatal outcomes, labour and delivery outcomes, and maternal outcomes and are reported narratively. A summary of meta-analysis findings is presented in Table 1.

Meta-analysis GDM:

There were 22 studies that reported associations between weight change and GDM (557,017 women)[24-45] and 19 could be pooled in the meta-analysis;[24-43] 18 studies could be pooled for meta-analysis of the association between GDM and weight gain in the preconception and interpregnancy periods,[25-42] and 13 studies for interpregnancy weight loss.[26,29,30,32,33,35-39,41-43] Overall women who gained weight before or between pregnancy were significantly more likely to develop GDM than those whose weight remained stable (OR 1.88, 95% CI 1.66, 2.14, I^2=87.8%, Figure 1). Conversely, women who lost weight between pregnancies were significantly less likely to develop GDM compared with women whose weight remained stable (OR 0.75, 95% CI 0.62, 0.92, $I^{2/span>}$=87.2%, Figure 2).

Four studies could be pooled for meta-analysis stratified by BMI category for interpregnancy weight gain[26,29,36,41] and four for weight loss;[29,36,41,43] no data were available for preconception weight change. There was a significantly increased odds of GDM associated with interpregnancy weight gain for both BMI subgroups, although higher among women with a BMI <25kg/m^2 than for BMI≥25kg/m^2 (Figure 3a). Interpregnancy weight loss was associated with a significant reduction in GDM for for BMI≥25kg/m^2 (Figure 3b).

Meta-analysis hypertensive disorders of pregnancy and preeclampsia:

There were 19 studies (451,127 women) that reported associations between weight change and hypertensive disorders of pregnancy and all were included in the meta-analysis.[25-28,32,35-37,40,41,43,46-53] There were 14 studies included in the meta-analysis of weight gain preconception or interpregnancy and hypertensive disorders (Fig S2a),[25-28,32,35-37,41,46-50] and seven for preeclampsia (Fig S3a);[35,40,41,50-53] both showed significantly increased odds compared with women whose weight remained stable (OR 1.46 95% CI 1.12, 1.91, I^2=94.9% and OR 1.92 95% CI 1.55, 2.37, I^2=93.6% respectively). The significant results remained in all subgroup analysis for preeclampsia, whereas for hypertensive disorders only the results for BMI change were significant and not for “other measures” of weight change.

There were nine studies included in the meta-analysis for interpregnancy weight loss and hypertensive disorders (Fig S2b)[26,32,35-37,41,43,47,50] and five for preeclampsia (Fig S3b),[35,41,50,52,53] both of which showed no significant difference between women who lost weight and those whose weight remained stable in the overall pooled analysis (OR 0.95, 95% CI 0.82, 1.10, I^2=58.5% and OR 1.23, 95% CI 0.81, 1.85, I^2=92.2% respectively). However, there was a significant decrease in odds of hypertensive disorders in the subgroup analysis for “other” measures of weight loss, and a significant increase in odds for preeclampsia in the weight loss within a specified BMI range subgroup, although this was using multiple data categories from a single study.

There were three studies that could be pooled for the meta-analysis of hypertensive disorders of pregnancy and interpregnancy weight gain stratified by maternal BMI,[26,36,41] and three for weight loss[36,41,43]. The increase in odds of hypertensive disorders associated with interpregnancy weight gain was only significant for BMI<25 kg/m^2 (OR 1.94, 95% CI 1.42, 2.64, I^2=59.9%) (Fig S2c), whereas there was only a significant reduction with interpregnancy weight loss for BMI≥25kg/m^2 (OR 0.85, 95% CI 0.79, 0.93, I^2=27.8%) (Fig S2d).

Meta-analysis LGA:

There were 15 studies that reported associations between weight change and LGA (411,781 women);[25-28,36,41,43,48,50,54-59] all were pooled in the meta-analysis for weight gain, and 13 for weight loss[28-

[30,35,40,47,51,53,58,60,61,63,64] [25-27,32,36,43,48,50,55,57,58,60,61] [28-30,35,39,46,51,53,58,60,61,63,64] [28-30,35,39,46,50,52,57,59,60,62,63] There was a significantly increased odds of LGA when women gained weight preconception or interpregnancy compared with women whose weight remained stable (OR 1.36, 95% CI 1.25, 1.49, I^2=92.2%), which remained for all subgroups (Figure 4). There was no significant association between LGA and weight loss in the overall analysis (OR 0.91, 95% CI 0.81, 1.03, I^2=93.0%), and the association was only significant for one subgroup (other measures of interpregnancy weight loss with no upper limit, Figure 5). There were five studies that reported data that could be pooled in the BMI stratified analysis for LGA and interpregnancy and preconception weight gain,[26,27,36,41,59] and six studies for weight loss.[27,36,41,43,58,59] There was a significantly increased odds of LGA with preconception or interpregnancy weight gain for both BMI groups but a larger effect size was observed for BMI <25kg/m^2 (OR 1.31, 95% CI 1.21, 1.41, I^2=17.2%) than for BMI ≥25kg/m^2 (OR 1.14, 95% CI 1.02, 1.29, I^2=5.1%) (Fig S4a). There was also a significantly reduced odds of LGA and preconception or interpregnancy weight loss with similar effect sizes for BMI <25 kg/m^2 (OR 0.78, 95% CI 0.76, 0.81, I^2=0.01%) and ≥25kg/m^2 (OR 0.81, 95% CI 0.79, 0.84, I^2=0.02%) (Fig S4b).

Meta-analysis SGA:

There were 13 studies that reported the association between weight change and SGA (141,087 women);[25-27,32,36,43,48,50,55,57,58,60,61] 13 were pooled in the meta-analysis for weight gain [25-27,32,36,43,48,50,55,57,58,60,61] and 12 for weight loss. [25-27,32,36,43,48,50,55,57,60,61] There was no significant associationetween weight gain and SGA in the overall pooled analysis (OR 1.00 95% CI 0.87, 1.14, I^2=62.3%) or subgroup analyses (Fig S5a); whereas there was a significantly increased odds for weight loss (OR 1.29, 95% CI 1.11, 1.50, I^2=89.9%), although this was not significant for the preconception subgroup (Fig S5b).

Two studies reported data that could be included in the BMI stratified meta-analysis for SGA and interpregnancy or preconception weight gain[27,36] and four for weight loss.[26,27,36,43] There was no significant association between weight gain and SGA for either BMI subgroup (Fig S5c), whereas there was a significantly increased odds for weight loss and SGA for women with a BM<25kg/m^2 (1.49, 95% CI 1.15, 1.92, I^2=90.7%) but not for BMI≥25kg/m^2 (Fig S5d).

Meta-analysis caesarean delivery and VBAC:

There were 13 studies reporting associations between interpregnancy weight change and caesarean delivery (523,195 women); [26,28,32,35,37,41,43,45,48,50,62-64] 11 were included in meta-analysis for weight gain and weight loss.[26,32,35,37,41,43,48,50,62-64] There was a significantly increased odds of caesarean with interpregnancy weight gain (OR 1.34, 95% CI 1.22, 1.48, I^2=91.2%) (Fig S6a), whereas there was no significant association for weight loss (OR 1.10, 95% CI 0.92, 1.31, I^2=93.7%) (Fig S6b). There were two studies that reported data which could be pooled into BMI stratified meta-analysis for interpregnancy weight gain,[26,41] and two for weight loss.[41,43] There was a significantly increased odds of caesarean and weight gain for both BMI subgroups with a greater effect size for BMI≥25kg/m^2 than for BMI<25kg/m^2 (OR 2.04, 95% CI 1.41, 2.95, I^2=N/A and OR 1.14, 95% CI 1.02, 1.28, I^2=60.4% respectively) (Fig S6c). There was only a significantly reduced odds of caesarean delivery with interpregnancy weight loss for BMI≥25kg/m^2 (OR 0.88, 95% CI 0.82, 0.96, I^2=58.6%) (Fig S6d).

Four studies reported data for VBAC (56,691 women)[32,35,65,66] and all could be pooled in the meta-analysis for interpregnancy weight gain and weight loss. There was a significantly reduced odds of successful VBAC and interpregnancy weight gain (OR 0.81, 95% CI 0.71, 0.92, I^2=58.3%) (Fig S7a), but not for weight loss (OR 0.98, 95% CI 0.86, 1.12, I^2=0%) (Fig S7b).

Meta-analysis stillbirth:

There were six studies reporting associations between interpregnancy weight change and stillbirth (1,129,998 women);[28,32,41,43,67,68] four could be pooled for meta-analysis of weight gain[28,32,67,68] and three for weight loss.[32,67,68] There was a significantly increased odds of stillbirth and weight gain (OR 1.49 95% CI 1.29, 1.72, I^2=53.9%) (Fig S8a) and weight loss (OR 1.22 95% CI 1.05, 1.42, I^2=0%) (Fig S8span style="font-family:'Times New Roman'">b). Subgroup analysis identified that this was only significant for studies which reported the BMI reduction within a specified range and not for BMI reduction with no upper limit. Two studies included data that could be included in the BMI stratified meta-analysis for stillbirth and weight gain and weight loss (Figs S8c and S8d).[41,67] There was a significantly increased odds of stillbirth and weight gain for both BMI subgroups, with similar effect sizes (BMI<25 kg/m² OR 1.25, 95% CI 1.11, 1.41, I^2=0%; BMI≥25 kg/m² OR 1.28, 95% CI 1.04, 1.58, I^2=25.9%) (Fig S8c). There was no significant difference in odds of stillbirth and weight loss for either BMI subgroup (Fig S8d).

Meta-analysis preterm:

There were 15 studies that reported associations between interpregnancy weight change and preterm delivery (1,016,240 women);[25,31,36,48,50,55,61,69-76] 10 were pooled for meta-analysis of weight gain[36,41,48,50,55,61,70,72,75,76] and nine for weight loss.[36,41,48,50,55,70,72,75,76] There was no significant association between interpregnancy BMI gain and preterm delivery in the overall analysis (OR 0.95 95% CI 0.89, 1.02, I^2=64.5%), or any of the subgroups (Fig S9a). There was some evidence of an increase in preterm delivery and interpregnancy weight loss (OR 1.06 95% CI 1.00, 1.13, I^2=22.4%), although this only remained significant for the subgroup when BMI loss was not restricted with an upper limit (Fig S9b). There were four studies that reported data which could be pooled in the BMI stratified meta-analysis for preterm delivery and interpregnancy weight gain and for weight loss.[36,41,70,76] There was only a significantly increased odds of preterm delivery and weight gain for BMI≥25k/m² (OR 1.11, 95% CI 1.03, 1.20, I^2=28.2%). Similarly, for weight loss there was only significant increased odd of preterm delivery for BMI<25 kg/m² (OR 1.21, 95% CI 1.11, 1.32, I^2=25.1%) (Fig S9c and S9d).

Meta-analysis low Apgar score/hemorrhage:

There were two studies reporting low Apgar score (528,303 women) [32,77] and two reported hemorrhage (26,388 women);[32,50] all were included in the meta-analysis for interpregnancy weight gain and weight loss. There was a significantly increased odds of low Apgar score and interpregnancy weight gain (OR 1.24, 95% CI 1.13, 1.36, I^2=23.65%) (Fig S10a), but no significant association with weight loss (OR 0.89, 95% CI 0.78, 1.01, I^2=0%) (Fig S10b). There was also no significant association between maternal hemorrhage and interpregnancy weight gain (OR 1.12, 95% CI 0.93, 1.34, I^2=0%) (Fig S11a) or loss and (OR 1.18, 95% CI 0.89, 1.56, I^2=0%) (Fig S11b).

Meta-regression, publication bias and sensitivity analysis:

Heterogeneity was high for multiple meta-analyses; some of this was partially explained by subgroup analysis which reduced heterogeneity to within the moderate or low ranges. Meta-regression was carried out to explore the remaining high levels of heterogeneity observed. Variables identified to be included in meta-regression for each outcome were further defined by the retrieved data: study design (e.g., sample size [grouped as <1000, 1000-5000, >5000, or unknown], prospective or retrospective, adjustments made in the analysis), population (e.g. country of study [grouped as North America, Europe, Scandinavia, or Australia], time period of study [grouped as before 1996, 1996-2004, or after 2004]), outcome definition and quality. There was no significant change to residual heterogeneity (I^2) for weight gain and GDM or preeclampsia (Tables S12a and S12h), or for weight loss and GDM, LGA or SGA (Tables S12b, S12d and S12e). However, there were variables that significantly contributed to heterogeneity for the remaining analyses. The variables that contributed to heterogeneity were the time period that data were collected (for analysis of LGA, caesarean delivery and hypertensive disorders of pregnancy), the geographical region of study (for analysis of caesarean delivery, preeclampsia and hypertensive disorders of pregnancy), sample size (for analysis of caesarean delivery and preeclampsia), and the study design being prospective or retrospective (for analysis of caesarean delivery) (Tables S12f-i). Although the residual heterogeneity was significantly reduced in these analyses, it still remained high with the exception of weight loss and preeclampsia (Table

S12i) where sample size explained almost all of the heterogeneity (I^2 reduced from 92.2% to 4.5%). We were not able to explore the extent to which differences in population characteristics or outcome definition contributed to the between study heterogeneity due to the lack of consistency in how these data were reported.

There was no evidence of publication bias for weight gain or loss and hypertensive disorders of pregnancy, preeclampsia, LGA, SGA, caesarean delivery, VBAC and stillbirth (Fig S2e-f, S3c-d, S4c-d, S5e-f, S6e-f, S7c-d, S8e-f). There was no evidence of publication bias for weight gain and GDM or preterm delivery (Figs S9e, S12a), but there was for weight loss (Figs S9f, S12b).

The sensitivity analysis suggests that meta-analysis results were robust for most outcomes, with limited impact on the effect size or significance of pooled results for weight gain and loss and GDM, hypertensive disorders, preeclampsia, LGA, SGA, caesarean and VBAC (Tables S13a-b, S14a-b, S15a-b, S16a-b, S17a-b, S18a-b, S19a-b); weight gain and stillbirth and preterm delivery but not for weight loss (Tables S20a-b, S21a-b); and not for subgroup analysis for GDM and weight loss (Table S13b).

Narrative synthesis:

The additional data for perinatal outcomes that could not be included in the meta-analysis due to data arising from a single study or the results from multiple studies not suitable for pooling, are reported in Table S22. Neonatal outcomes included NICU admission (n=280),[28] low birth weight (categorized according to sex-dependent z-scores, n=12,058),[58] preterm and recurrent preterm birth (dataset did not differentiate between the two outcomes; n=1,241),[71] recurrent preterm birth only (n=7,674),[69,73] hypoglycemia (n=1,048),[32] respiratory distress (n=1,048),[32] neonatal seizures (n=1,071),[77] meconium aspiration (n=757),[77] neonatal, postneonatal and infant mortality (n= 515,252),[67] infant anthropometrics (n=73),[45] perinatal death (n=24,795),[43] a composite measure of congenital anomalies (n=45,439),[26,43] spina bifida (n=5,060),[78] conotruncal heart defects (n=1,685),[79] gastroschisis (n=5,343)[80] and cleft lip (n= 220,328).[81] For neonatal outcomes, an interpregnancy gain or loss of ≥1 BMI unit appears to be associated with an increased risk for spina bifida,[78] gastroschisis,[80] and respiratory distress[32] compared to stable weight. No associations were found between preconception or interpregnancy weight loss or gain and the following labour and delivery outcomes: 4th degree perineal tears (n=2,860),[32] episiotomy (n=2,860),[32] shoulder dystocia (n=2,860),[32] instrumental delivery (1 study, n=23,329)[50], and caesarean delivery (n=73).[45] Placental weight (n=5,079)[50] was positively correlated with weight change, as women who gained or lost weight preconception or interpregnancy had heavier or lighter placentas respectively, than women who had stable weight. Maternal outcomes associated with an increased risk following weight gain were pregnancy loss (1 study, n=995),[82] maternal morbidity (1 study, unknown sample size)[61], GDM (n=73),[45] recurrent GDM (n=501),[44] and GWG (n=799).[83]

Discussion:

This systematic review and meta-analysis aimed to summarize the effect of preconception and interpregnancy weight change on perinatal health outcomes. The search yielded data pertaining to 34 outcomes. Meta-analysis identified evidence of a significantly increased risk of GDM, LGA, preeclampsia, and hypertensive disorders following preconception and interpregnancy weight gain, irrespective of preconception BMI. Interpregnancy weight gain also significantly increased the odds for caesarean delivery, low APGAR scores, stillbirth, and unsuccessful VBAC, regardless of prpregnancy BMI; there was a lack of data available for preconception weight gain and these outcomes. Interpregnancy weight loss significantly increased the risk for SGA and preterm delivery; however, these associations were not observed with preconception weight loss. When stratified by BMI, women with a BMI ≥ 25.0 kg/m^2 who gained weight between pregnancies had increased odds of hypertensive disorders, preterm birth and caesarean delivery. Women with a BMI ≤ 25.0 kg/m^2 who gained weight between pregnancies were at increased risk for GDM, hypertensive disorders, and caesarean delivery. When stratified by BMI, interpregnancy weight loss reduced the risk for GDM, hypertensive disorders, and caesarean delivery for women who had a BMI ≥ 25.0 kg/m^2. For women who had a BMI < 25.0 kg/m^2, weight loss interpregnancy or preconception was associated with increased risk of SGA and reduced risk for LGA. Additionally, interpregnancy weight loss for women who had a BMI < 25.0 kg/m^2 was associated with increased risk for preterm birth, and reduced risk for GDM. A narrative synthesis of data that could not be included in meta-analysis suggests that interpregnancy weight gain is associated with increased risk of maternal morbidity, pregnancy loss, neonatal seizures and meconium aspirations. Overall, these findings affirm that weight change before pregnancy can influence perinatal outcomes, and therefore, weight management support and recommendations should be offered to all women prior to pregnancy as a part of standard preconception or interpregnancy healthcare.

This review adds novel data building on the work of three previous systematic reviews that assessed only interpregnancy weight change and perinatal outcomes.[10-12] Our synthesis has incorporated results from an aditional 30 studies which were not included in previous reviews and data for 34 outcomes, of which 26 have not been previously reviewed. Notably, the results of this review are relevant to women of all parities. We also performed subgroup analysis and meta-regression to explore heterogeneity, which is a novel contribution to the field, although there were some *a priori* factors that we were not able to explore. In line with previous findings,[10-12] this review identified an increased odds for GDM, hypertensive disorders, preeclampsia, LGA, and caesarean delivery following interpregnancy weight gain. Our findings extend current data and suggest that preconception weight gain also increases the odds of women developing GDM and preeclampsia. Additionally, our findings add that interpregnancy weight loss can increase the risk for SGA and preterm delivery, irrespective of BMI. Given that most women are recommended or want to lose postpartum weight before their next pregnancy,[6-8] this finding illustrates the need to understand mechanisms surrounding weight loss to prevent harm, such as SGA and preterm delivery in subsequent pregnancies. Specific weight loss mechanisms that require further investigation include the rate of weight loss, methods used to lose weight, whether weight loss was a result of illness, and the time period of when weight loss was measured. Collectively, these results highlight the need for effective preconception and interpregnancy weight management support regardless of women's parity.

Limited studies have investigated the consequences of preconception weight change compared with interpregnancy. A recent scoping review that aimed to summarize obesity prevention behavioral interventions for women of childbearing age identified that most studies have only targeted postpartum weight management, and therefore nulliparous women are not included.[84] We most often see the inclusion of nulliparous women in infertility weight-management interventions.[85,86] However, women who are not seeking fertility treatment may also require weight management support. Although an exact prevalence for weight loss attempts prior to pregnancy is not available, more than 40% of adults try weight management annually comprising primarily of women.[16] From these statistics we can infer that preconception weight support should not be reserved only for women seeking fertility care.

Additionally, no studies reported on the potential effects of pre-pregnancy weight change on maternal mental health outcomes. Poor preconception mental health is associated with perinatal complications such as low birthweight, hypertensive disorders, high blood sugar, and premature labour.[87] Furthermore, prenatal depression is positively correlated with maternal BMI, positioning women with obesity at the highest risk for detrimental mental health outcomes during pregnancy.[88] The desire to lose weight among women is also associated with suboptimal mental health.[89] Specifically, data from non-pregnant women undergoing weight loss interventions suggests a negative correlation between self-perceived control over their weight and deleterious psychological variables like shame and self-criticism.[90] It may be that women experiencing preconception weight change, whether intentional or not, can also be at an increased risk for poor prenatal mental health outcomes, and this warrants further investigation.

Studies have shown that preconception obesity is a risk factor for perinatal complications,[1,2] and accordingly, maternal obesity guidelines suggest weight loss before conception to improve health outcomes.[5-7] In our review, sub-analyses were performed considering prepregnancy BMI. Women with an elevated BMI who gained weight between pregnancies had an increased odds of hypertensive disorders and caesarean deliveries in subsequent pregnancies, whereas weight loss between pregnancies reduced the odds of GDM, hypertensive disorders, and caesarean deliveries. Of note, we could not assess the relationship between these outcomes and preconception weight loss. Furthermore, irrespective of BMI, there was an increased risk for SGA (interpregnancy) and preterm loss (preconception and interpregnancy) with weight loss. Unfortunately, due to limited data on preconception weight loss, high heterogeneity, and variable methods of measuring weight loss before pregnancy, a recommendation for an amount of weight that women should aim to lose or not lose in a given timeframe to improve outcomes cannot be confirmed. Another gap identified in our review was the lack of studies from Asian, South American and African countries. Ethnicity and sociocultural factors may influence body ideals before and during pregnancy, weight management behaviours, and risk of perinatal complications, and therefore diverse population representation is necessary in future research. Lastly, all analyses were compared to stable weight as the reference (i.e., no change or no more than 1 BMI unit change) before pregnancy. Perhaps these findings may suggest that instead of recommending weight loss, we should consider highlighting the importance of improving health behaviors to establish a stable preconception weight.

Strengths of this review include the rigorous search strategy, including supplementary searches that involved hand searches of reference and citation lists. All screening, data extraction, and quality assessment were carried out by two independent investigators. In addition, included studies were of medium to high quality. To our knowledge, this is the first meta-analysis that has incorporated preconception weight change, and therefore findings apply to women of any parity. The results from our review are limited by the few studies that evaluated preconception weight change in comparison to interpregnancy, and none that exclusively included nulliparous women. Sources of heterogeneity between studies that were not explored due to lack of data may also have influenced findings, such as maternal ethnicity, behavioural factors (e.g., diet, physical activity, smoking), socioeconomic status, and women with prenatal complications; although some studies did adjust for these variables or excluded women with pre-existing complications from their analysis. Additionally, variability in outcome definitions across studies (for example diagnosis criteria of GDM) may also be a limitation, and due to limited/inconsistent reporting of data a meta-regression to assess the impact of these differences was not completed. Similarly, we relied on how data were reported in studies to categorize the outcomes, and as a result, in some cases were not able to differentiate between specific types of maternal or newborn outcomes (e.g., spontaneous versus medically indicated preterm delivery). Moreover, the review was restricted to studies that assessed short term outcomes (pregnancy health outcomes and birth outcomes), and therefore we did not explore potential longitudinal implications of prepregnancy weight change on maternal and child health, and this may be an area for further investigation.

Conclusion:

Our systematic review and meta-analysis showed an increased risk for perinatal complications following preconception or interpregnancy weight instability. Regardless of prepregnancy BMI, women who gain weight preconception or between pregnancies have an increased odds of GDM, hypertensive disorders, preeclampsia, and LGA. Additionally, weight loss between pregnancies increases the risk for SGA, while interpregnancy or preconception weight loss can increase the risk for preterm birth. Further studies are needed explicitly evaluating the preconception period, and the impact of weight change on maternal mental health outcomes. This review emphasizes the need for effective preconception and interpregnancy weight management support to prevent perinatal complications.

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Appendix 2. Ethics Approval Certificate for EMat Health Survey Study

CHEO RESEARCH INSTITUTE
INSTITUT DE RECHERCHE

Research Ethics Board
2017 Annual Renewal (Delegated)

Principal Investigator: Dr. Gary Goldfield
REB Protocol No: 14/183X
Romeo File No: 20140503
Project Title: CHEOREB# 14/183X - Women's Perceptions of the Current Weight Gain Guidelines during Pregnancy
Primary Affiliation: HALO\HALO
Protocol Status: Active
Approval Date: November 27, 2017Approval Valid Until: December 15, 2018
Annual Renewal Submission Deadline:November 15, 2018
Documents Reviewed & Approved:

Document Name	Comments	Version Date
Protocol	Protocol unchanged	2014/10/17
Consent Form	Consent and questionnaire linked	2016/12/14

This is to notify you that the CHEO REB has granted approval to the renewal for the above named research study for a period of one year. The renewal was reviewed and approved by the Chair or a delegate of the Chair. Decisions made by the Chair under delegated review are ratified by the full Board at its subsequent meeting.

Appendix 3. Ethics Approval Certificate for SmartMoms Canada Study

10/12/2020

Université d'Ottawa
Bureau d'éthique et d'intégrité de la recherche

University of Ottawa
Office of Research Ethics and Integrity

CERTIFICAT D'APPROBATION ÉTHIQUE I CERTIFICATE OF ETHICS APPROVAL

Numéro du dossier / Ethics File Number	H-09-19-4795
Titre du projet / Project Title	SmartMoms Canada: An evaluation of a pregnancy-specific mobile health application to manage gestational weight gain
Type de projet / Project Type	Recherche de professeur / Professor's research project
Statut du projet / Project Status	Renouvelé / Renewed
Date d'approbation (jj/mm/aaaa) / Approval Date (dd/mm/yyyy)	18/11/2019
Date d'expiration (jj/mm/aaaa) / Expiry Date (dd/mm/yyyy)	17/11/2021

Équipe de recherche / Research Team

Chercheur / Researcher	**Affiliation**	**Role**
Kristi ADAMO	École des sciences de l'activité physique / School of Human Kinetics	Chercheur Principal / Principal Investigator
Sara SCREMIN SOUZA	École des sciences de l'activité physique / School of Human Kinetics	Étudiant-chercheur / Student-researcher
Kevin SEMENIUK	École des sciences de l'activité physique / School of Human Kinetics	Coordonnateur de recherche / Research Coordinator
Danilo FERNANDES DA SILVA	École des sciences de l'activité physique / School of Human Kinetics	Assistant de recherche / Research Assistant

Conditions spéciales ou commentaires / Special conditions or comments

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