Postpartum lifestyle, weight and body composition

Margriet Bijlholt

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Voorjaar 2022

Drie Ginkgobomen op een stukje aard:
Ze zijn geplant voor't huis, door mijn papa.
Frisgroen in't voorjaar, heldergroen daarna,
En herfst, dan kleurt een wolk van goud de straat.

Hij leeft steeds door, die oudste boom op aard.
Oertijd, komeetinslag: leeft vóór en na.
De boom doorstond de bom Hiroshima.
Een soort die't eeuwig leven goed bewaart.

In welke tijd is d'aarde nu beland?
Al zie ik Lente, k'hoor een oud geluid.
Het voorspel van een grote wereldbrand?

Maar ook: de merel zingt, hij roept zijn bruid.
Het eeuwig leven blijft het zinsverband!
En Lente, Ginkgo's, ik, wij lopen uit.

A.G.B.

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Postpartum lifestyle, weight and body composition

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CHAPTER 1.

General introduction

There is increasing evidence that maternal perinatal weight and lifestyle (i.e., during and after pregnancy) play a crucial role in long-term maternal and child health. In the reproductive phase, the weight and body composition of women will undergo important changes that will affect the long-term weight of women, and therefore also their weight-related health risk profile. Crucial elements of this evolution are **(1) pre-pregnancy body mass index (BMI)**, i.e. the body mass index right before the start of pregnancy, **(2) gestational weight gain (GWG)**, i.e. the amount of weight gained during pregnancy and **(3) postpartum weight retention (PPWR)**, i.e. the amount of GWG that is retained after pregnancy. Figure 1.1 schematically illustrates the descriptions of these three concepts. **Lifestyle behaviors** are important determinants of weight-related outcomes and therefore **lifestyle interventions** are important strategies to optimize weight management in the perinatal period. Figure 1.2 provides a conceptual framework that illustrates this. In this introduction, the concepts of this framework are elaborated on. First, background is provided on perinatal weight and body composition. Subsequently, lifestyle behaviors and lifestyle interventions are outlined. Furthermore, the potential of m-health is described. Gaps with regard to perinatal lifestyle and interventions are identified, and the aims of the current thesis are outlined.

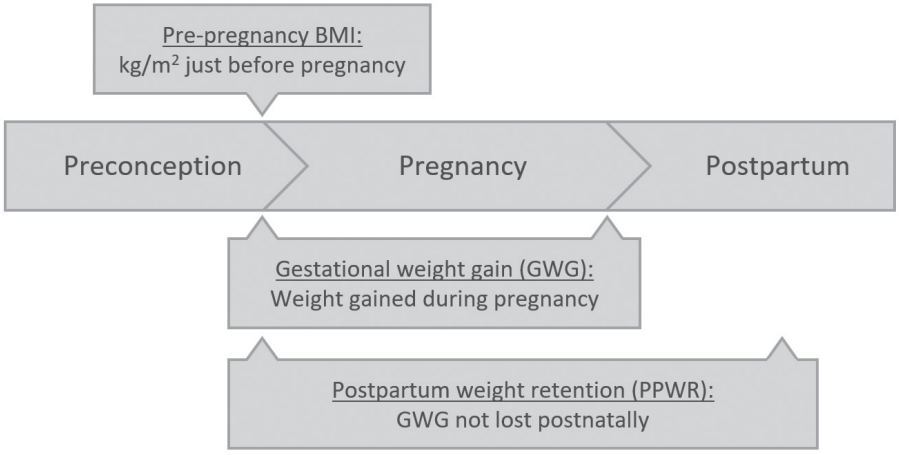

Figure 1.1. Timeline of pre-pregnancy BMI, gestational weight gain and postpartum weight retention.

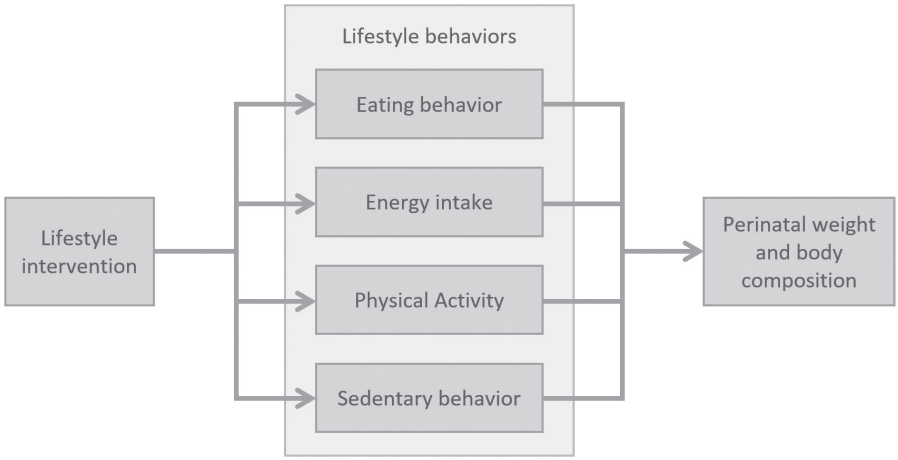

Figure 1.2. Conceptual framework of perinatal weight and body composition

Perinatal weight and body composition

Pre-pregnancy body mass index

Body mass index (BMI) is a measure for nutritional status and is calculated by dividing weight in kilograms by the square height in meters (kg/m2) [1]. A BMI value lower than 18.5 is considered as underweight, 18.5-24.9 as normal weight, 25-29.9 as overweight, and 30 and higher as obesity. Three classes of obesity are furthermore distinguished, obesity class I representing a BMI of 30-34.9, obesity class II representing a BMI of 35-39.9, and obesity class III representing a BMI of 40 and higher (Table 1.1) [1].

Table 1.1. Body mass index categories. From: World Health Organization [1].

Body mass index in kg/m²	Body mass index category
< 18.5	Underweight
18.5-24.9	Normal weight
25.0-29.9	Overweight
30.0-34.9	Obesity class I
35.0-39.9	Obesity class II
≥ 40	Obesity class III

BMI values within the underweight range as well as the overweight and obesity ranges are related to adverse health outcomes. Health consequences of underweight in adults include amongst others fertility issues, weakened immune system and subsequent proneness to infections, micronutrient deficiencies and related diseases such as osteoporosis and anemia [2]. Health consequences of overweight and obesity include cardiovascular diseases, type 2 diabetes mellitus, and cancer [3].

Overweight and obesity are far more common conditions than underweight. To illustrate, the prevalence of underweight among Belgian women is 2%, whereas the prevalence of overweight and obesity are respectively 27.3% and 10.6% among Belgian women aged 18-39 years [4]. Among women who become pregnant, overweight and obesity rates are similarly high. Figure 1.2 displays the rates of women who start pregnancy with a BMI in the underweight, normal weight, overweight and obesity category. There is a rising trend of overweight and obesity before pregnancy. Between 2011 and 2020, the rate of women who commence pregnancy with a BMI of 25 or higher increased from 32.5% to 39.8% [5]. Socio-demographic risk factors for obesity include lower level of education, lower socio-economic status, and non-European ethnicity [6].

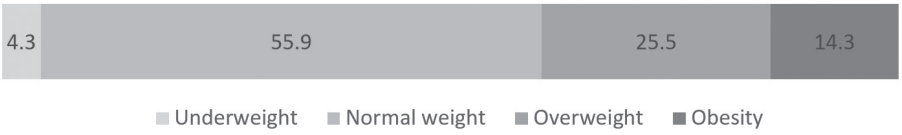

Figure 1.3. BMI category of women at the start of pregnancy in Flanders, Belgium (n = 54 020). Source: Devlieger, Goemaes & Laubach, 2021 [5].

Maternal overweight and obesity at the start of pregnancy are important risk factors for a multitude of adverse health outcomes. Women with obesity more often face fertility issues, including lower probability to conceive, longer time to conceive, and reduced success rates of conception treatments [7-9]. Also, early miscarriage and recurrent pregnancy loss are more prevalent among women with pre-pregnancy obesity [10, 11].

During pregnancy, pre-pregnancy overweight and obesity are associated with an increased risk of gestational diabetes, pregnancy-induced hypertension, pre-eclampsia, depressive symptoms, excessive gestational weight gain, cesarean section, and extreme preterm birth [9, 12-15].

After delivery, women with pre-pregnancy overweight or obesity are at increased risk of postpartum hemorrhage [12]. Overweight and obesity are also associated with depressive symptoms [16]. In addition, these women are less likely to initiate breastfeeding and more likely to cease breastfeeding early [17]. Furthermore, they are at increased risk of postpartum weight retention, even if they had an adequate weight gain during pregnancy [18].

Neonates born to mothers with obesity are also at increased risk of adverse health outcomes. They more often have an APGAR score lower than 7 at 5 minutes, and are more often admitted to the neonatal intensive care unit [12]. Besides, infants of mothers with overweight or obesity are more often born macrosomic (birth weight > 4000 g) or large for gestational age (birth weight >90th percentile for gestational age) [12, 19]. On the longer term, these infants have an increased risk of obesity themselves, also referred to as the intergenerational cycle of obesity [20, 21]. In addition, infants of women with obesity are at increased risk of developing cardiometabolic diseases [22]. The Developmental Origins of Health and Disease (DOHaD) hypothesis suggests that these long-term morbidities in the offspring originate in early life [23]. Fetal adaptation to its *in utero* environment, i.e. fetal programming, has long-term consequences for the organ's functioning and metabolism and might therefore result in obesity and cardiometabolic diseases [23]. Maternal obesity as well as maternal lifestyle are crucial contributors to an unhealthy *in utero* environment [24, 25]. It is suggested that fetal programming is a result of epigenetic changes that take place in response to the adverse *in utero* environment [25, 26]. Furthermore, a growing body of evidence suggests that placental changes are probably partly responsible for these long-term morbidities in the offspring. Pre-pregnancy overweight and obesity are determinants of placental changes in terms of structure and function. These changes result, amongst others, in increased lipid accumulation in the placenta and subsequent increased lipid supply to the fetus. This might result in an expansion of adipose tissue in the offspring [25], which increases the susceptibility to develop obesity in later life [26]

Overweight and obesity at the start of pregnancy are thus problematic conditions because they entail an increased risk of various adverse outcomes in both the mother as well as the offspring. The rising trends in BMI makes the issue even more urgent [5, 27, 28].

Gestational weight gain

A second crucial determinant for long-term weight and health of women is the weight gained during pregnancy, i.e. gestational weight gain (GWG). Table 1.2 shows the guidelines for adequate GWG per pre-pregnancy BMI category that were formulated by The National Academy of Medicine (formerly the Institute of Medicine) [29]. These guidelines are based on optimal health outcomes for mother and infant; risk for adverse health outcomes is lowest when pregnant women have a GWG within the adequate range.

Table 1.2. Inadequate, adequate and excessive gestational weight gain. Source: National Research Council, 2009[29]

Pre-pregnancy BMI category	Pre-pregnancy BMI in kg/m²	Inadequate gestational weight gain	Adequate gestational weight gain	Excessive gestational weight gain
Underweight	<18.5	<12.5 kg	12.5-18 kg	>18 kg
Normal weight	18.5-24.9	<11.5 kg	11.5-16 kg	>16 kg
Overweight	25.0-29.9	<7 kg	7-11.5 kg	>11.5 kg
Obesity	≥30	<5 kg	5-9 kg	>9 kg

In these guidelines for optimal GWG, no distinction is made in severity of obesity, i.e. obesity class I, II or III. However, it is debated that this distinction should be made, as risks of complications differ between the obesity classes. In a large population-based study in Flanders (the northern region of Belgium), it was investigated at which GWG the probability of complications was lowest. This was done for each BMI category separately. It was observed that women with pre-pregnancy underweight had lowest probability of complications at a GWG of 21 kg, women with normal weight at a GWG of 14 kg, women with overweight at a GWG of 8 kg, women with obesity class I at a GWG of 0 kg, women with obesity class II at a GWG of -4 kg, and women with obesity class III at a GWG of -5 kg [30]. Especially among women with a BMI in the three obesity classes, this 'optimal' GWG largely differs from the international guideline of adequate GWG as presented in Table 1.2.

Gestational weight gain is driven by several physiologic changes that occur during pregnancy. These physiologic processes are necessary for fetal growth and development, maternal anatomic and physiologic changes, and preparation for lactation [25, 31]. In early pregnancy, insulin sensitivity increases. This generates an increase of glucose uptake into adipose tissue, which is necessary for enhanced energy demands in the second half of pregnancy. Later in pregnancy, there is rather a low level of insulin

resistance, which results in enhanced blood glucose levels. This enhances transportation of glucose through the placenta to the fetus for fetal growth. Simultaneously, the state of insulin resistance prompts utilization of fat stores [25]. However, obesity is associated with metabolic dysregulation, which implies that metabolic homeostasis cannot be maintained [32, 33]. This might amongst others result in higher gestational weight gain [33].

Approximately 40 to 50 percent of pregnant women exceed the ideal GWG [18, 34, 35]. Excessive GWG is an important risk factor for adverse outcomes in both the mother as well as the infant. Adverse maternal health outcomes of excessive GWG include gestational diabetes, pregnancy-induced hypertension, caesarian section and large for gestational age infants [36, 37]. This is critical, as these complications are related to a multitude of short-term and long-term health consequences for both mother and her offspring [38-41]. Also, it is challenging for women with excessive GWG to lose all pregnancy weight in the postpartum, resulting in an increased risk of postpartum weight retention (PPWR) [42-44]. To illustrate, in a study among first-time mothers (n=2500), 1 in 3 women who had excessive GWG had ≥10 pounds (≥4.5 kg) PPWR at 1 year after delivery [43]. Eventually, PPWR might contribute to long-term obesity [45, 46].

Postpartum weight

Postpartum weight retention (PPWR) is the difference between weight in postpartum and weight before pregnancy, i.e., the amount of pregnancy weight that one has not lost. At present, there is no uniform definition of the duration of the postpartum period. Common time points for reporting postpartum weight are six weeks, six months and twelve months postpartum [43, 47, 48]. Alternatively, PPWR can be measured and reported at the start of the subsequent pregnancy, although the length of this time period differs between women [44]. Often, a threshold of 5 kg or 10 pounds (4.5 kg) is applied, above which PPWR is perceived as substantial [43, 44].

Recent studies show that almost one in four women has considerable PPWR (i.e., >10 pounds or >5 kg) at 12 months postpartum as well as at the start of a subsequent pregnancy [43, 44]. This has potential health consequences, as PPWR is associated with several maternal and infant morbidities, as well as complications in a subsequent pregnancy. Long-term PPWR might result in overweight or obesity, which is associated with type 2 diabetes, cardiovascular disease and cancer [49, 50]. In addition, PPWR increases the risk of gestational diabetes, pregnancy-induced hypertension, preeclampsia, caesarian section, and a large for gestational age infant in a subsequent

pregnancy [51-53]. Besides excessive GWG, other risk factors for PPWR include higher pre-pregnancy BMI, lower level of education, and poverty [18, 43]. Lifestyle behaviors such as energy intake and physical activity are also associated with postpartum weight [43, 54] and breastfeeding potentially also plays a role in postpartum weight, although the evidence is contradictory [43, 55].

Body composition

Fat mass and waist circumference are valuable body composition measures that are complementary to body weight and BMI [56]. Increased fat mass is related to poorer cardiovascular health, even in those with a healthy BMI [57-59]. Waist circumference is a valuable measure to indicate central adiposity, which is also a risk factor for cardiovascular disease [59-61]. An increasing fat mass during pregnancy is normal and necessary for maternal and fetal energy demands [62, 63]. However, excessively high fat mass gains during pregnancy might result in long-term fat retention after delivery. Excessive GWG is a known risk factor for short- and long-term postpartum fat retention [64, 65]. Studies reported that breastfeeding practices did not affect postpartum fat mass [63, 64], whereas another study showed that overall fat mass as well as visceral fat were greater in lactating women than in non-lactating women [66]. This might be explained by an increased energy intake in lactating women and subsequent fat storage [67].

Bio-electrical impedance analysis (BIA) is a non-invasive, quick and low-cost method to measure body composition including fat mass [68]. Phase angle is another parameter derived from BIA, which represents the ratio of measured reactance and resistance and is used as a prognostic tool for a number of diseases [69, 70]. Phase angle assesses the amount and quality of soft tissue mass [71]. It indicates how body water is distributed between intra- and extracellular spaces. Higher phase angle values reflect higher cellularity, membrane integrity and better cell function [69]. Age, gender and BMI influence phase angle. There are considerable differences between reference values from different populations [69, 71]. It is therefore recommended that individual results should be compared against population-specific reference values [72]. A limited number of studies reported phase angle values or changes in phase angle over time in pregnancy or in the postpartum period [72-75]. Knowledge on phase angle evolution in the perinatal period in combination with knowledge on the association between phase angle and long-term health outcomes could inform for example future screening opportunities.

Lifestyle behaviors and lifestyle interventions

Lifestyle behaviors such as energy intake, eating behavior, physical activity and sedentary behavior are important determinants of (perinatal) weight and form therefore important elements of lifestyle interventions that target weight management. Moreover, regardless of weight, adopting a healthy lifestyle is vital in the prevention of long-term adverse psychological, metabolic and cardiovascular health outcomes [76-80]. In the perinatal time window, lifestyle interventions can focus on the pregnancy period, preconception period, or postpartum period. In the subsequent paragraphs, lifestyle behaviors and their relations with (perinatal) weight are discussed. Next, the potential of interventions in the different perinatal phases is highlighted.

Lifestyle behaviors in relation to perinatal weight

Energy intake is widely recognized to affect (perinatal) weight. Reducing energy intake is therefore likely to aid weight loss in the perinatal time window, although caution should be taken to meet the energy demands of growth during pregnancy and lactation in the postpartum period, if applicable [81, 82]. Some interventions rather focus on macronutrient intake or certain food groups, such as meeting fruit and vegetable intake requirements [83-85].

Relatively less studied is the concept of **eating behavior**, which relates to the internal and external circumstances under which food intake takes place. Several types of eating behaviors can be distinguished: restrained eating, external eating, emotional eating, cravings, disinhibition or uncontrolled eating, intuitive eating and mindful eating [86-89]. Stronger presence of negative eating behaviors such as emotional eating is associated with higher BMI and weight gain in general populations [90, 91]. Eating behaviors are probably also associated with GWG and PWPR. A systematic review showed that restrained eating (i.e. the conscious restriction of food intake in order to control body weight or to promote weight loss [92]), is a risk factor for excessive GWG [93]. In addition, eating behaviors, especially emotional eating, are associated with several psychologic assets. To illustrate, distress, anxiety, depression, poor emotion regulation skills, emotion-oriented coping, and avoidance distraction are associated with emotional eating [94-96]. Due to circumstances such as hormonal changes and sleep deprivation in pregnancy and postpartum, some of these psychological assets might be expressed even more during pregnancy and postpartum. This reinforces the proposition that eating behaviors play an important role during pregnancy and postpartum. However, no reviews are available in the literature on other types of eating behaviors in relation to GWG and neither are associations between eating behaviors and PPWR reviewed previously. An overview of

which eating behaviors are related to GWG and PPWR and which are not could provide insight into which eating behaviors are important to target in future lifestyle interventions.

Both in general populations as well as in pregnant populations there is extensive evidence that **physical activity** is related to weight [76, 97, 98]. However, there is little evidence that physical activity impacts weight in the postpartum period [76]. In a cohort of women with obesity, a moderate to high physical activity level was found to be an important determinant of postpartum weight loss at 6 months postpartum [99]. Despite the limited evidence for its effectiveness, postpartum lifestyle interventions commonly incorporate a physical activity component [100, 101]. Interventions combining healthy eating and physical activity components are shown to be most effective [100, 102].

Sedentary behavior is a relatively newer concept and refers to the time spent sitting. Even physically active individuals can have a high sedentary time. This is related to adverse outcomes such as increased metabolic disorders including cardiovascular disease and type 2 diabetes [103, 104]. Pregnant women spend on average at least half of their time in sedentary activities, which is similar to the general population [104]. Although no literature is available on time spent sitting in postpartum, it is likely that postpartum women spend at least as much time on sedentary activities as pregnant women. For some individuals, and especially in early postpartum, this might be even more time due to recovery from childbirth and time spent on infant (breast)feeding [105].

Perinatal time windows suitable for lifestyle intervention

Changing lifestyle habits and maintaining a healthier lifestyle on the long term is a challenge. Pregnancy is perceived as a 'teachable moment', during which many women are more motivated to make an effort for a healthier lifestyle [106, 107]. Likewise, the transition to parenthood that continues into the postpartum period can also be perceived as such a teachable moment. The perinatal period therefore forms an opportunity for lifestyle intervention. Pregnancy, the preconception period and the postpartum period form windows of opportunity for lifestyle intervention and are outlined below. As highlighted in the heuristic model for teachable moments by McBride and colleagues, behavior change is during teachable moments expedited by increased motivation, skill acquisition and self-efficacy [107]. These determinants of behavior change thus form important aspects to be taken into consideration in lifestyle interventions.

Several lifestyle interventions have previously been conducted during **pregnancy** aiming to reduce GWG and the aforementioned complications. These interventions were generally effective in the reduction of GWG: an individual patient data meta-analysis showed a GWG reduction of 0.7 kg based on 33 studies (n=9320) [108]. However, the effective reduction of GWG by lifestyle intervention did not result in a reduced PPWR on the long term (i.e., up to 3 years post-delivery) nor in reduced child BMI [109]. Besides, there is conflicting evidence on whether or not lifestyle interventions in pregnancy affect complications such as gestational diabetes, pregnancy-induced hypertension, caesarian section and large for gestational age infants [100, 102, 108, 110]. It is suggested that interventions commencing during pregnancy are not timely to reduce these complications. A healthy lifestyle and weight at the very beginning of pregnancy are supposedly required to impact pregnancy-related complications. Consequently, preconception interventions are needed [36, 100, 108].

Few **preconception** lifestyle interventions, i.e. targeting healthy eating and/or physical activity, are described in the literature. Targeting women preconceptionally is hard, as it is generally not known when the preconception phase exactly starts [100]. It is uncommon that women reach out to their care givers to prepare for a healthy prospective pregnancy. Moreover, it is estimated that 1 in 5 pregnancies is unintended, impeding preconception intervention [111]. Consequently, most preconception lifestyle interventions focus on a specific target group of people who do reach out to care givers or who are already in the care system, for example due to fertility issues or pre-existing chronic disease [112]. The majority of preconception interventions aim to reduce alcohol consumption or promote folic acid intake. Fewer interventions aim to improve lifestyle behaviors such as healthy eating and physical activity. In a review of 29 preconception interventions it was found that part of these were successful in increasing knowledge of preconception health. However, more knowledge does not necessarily imply subsequent behavior change. Only one study in the review reported improved nutrition and physical activity as a result of the preconception intervention [113]. Although it is suggested that preconception interventions have the potential to reduce complications in pregnancy and longer-term adverse health outcomes, no preconception intervention studies were identified that reported effects on these longer-term outcomes [113-115].

An alternative approach is to perceive the **postpartum** period as the preconception phase of a subsequent pregnancy. This '**inter-pregnancy**' phase is a window of opportunity to work on a healthy lifestyle and weight in preparation for the subsequent pregnancy. An additional advantage of this

approach is that women at increased risk of complications can be selected based on medical data from the previous pregnancy. A disadvantage of this approach is, however, that the first pregnancy is not targeted. A review reported that postpartum lifestyle interventions achieved a PPWR reduction of 2.3 to 2.6 kg, although the included studies were of poor quality [102]. Longer-term outcomes of postpartum lifestyle interventions such as complications in subsequent pregnancies were not reported [102]. Postpartum interventions that combine healthy eating and physical activity as focal points are found to be most effective. Whereas diet only interventions achieved a mean weight loss of -2.3 kg [95% CI -5.27, 0.67] and physical activity only interventions a mean weight loss of -0.78 kg [95% CI -1.73, 0.16], combined interventions achieved a mean weight loss of -3.14 kg [95% CI -4.33, -1.95] [116]. Furthermore, postpartum lifestyle interventions targeting high-risk groups of women with overweight or obesity achieved larger weight loss (-3.17 kg [95% CI -4.45, -1.89]) compared to interventions that included all BMI-groups (-1.04 [95% CI -1.74, -0.34]) [116]. Besides, group interventions are potentially more effective than individually delivered lifestyle interventions, although evidence is conflicting [116, 117]. Lifestyle interventions that employ m-health are furthermore promising for postpartum weight management.

The potential of m-health

Interventions delivered digitally through mobile devices such as smartphones are referred to as m-health (i.e., mobile health) [118]. The term e-health (i.e., electronic health) is sometimes used as an umbrella term that covers m-health but for example also includes web pages [119]. Important advantages of e-health and more specifically m-health are that they can facilitate access to health care and is less resource-demanding than usual care [120, 121]. In terms of the heuristic model of teachable moments [107], m-health potentially could facilitate the process of behavior change by increasing motivation and self-efficacy. To illustrate, motivational messages could reinforce motivation to change behavior. In addition, digitally delivered interventions in other settings are shown to improve self-efficacy by enhancing self-management [122]. M-health interventions are found to be effective in reducing weight, increasing fruit and vegetable intake, and increasing physical activity in general populations [123]. A limited number of studies evaluated m-health during pregnancy and in the postpartum period. Although evidence is currently inconclusive, m-health seems to be an effective tool for weight management in the perinatal phases [124]. Self-monitoring of weight appears an important element of m-health interventions targeting weight loss [119, 120, 125]. Furthermore, feedback on performance and goal setting are suggested to be important elements of

m-health interventions [120]. Besides, the emerging evidence on blended interventions (i.e., a combination of e-health or m-health and face-to-face intervention [126]) suggests that this type of intervention is more effective for (perinatal) weight management than e-health or m-health interventions alone [100, 119, 120].

Aims of the current thesis

Several gaps were identified in the current state of the art with regard to perinatal weight, lifestyle and intervention. Firstly, there is currently a lack of insight into the role of eating behaviors in perinatal weight fluctuations. Secondly, the postpartum period appears to be an opportune time for lifestyle intervention, but only a limited number of lifestyle interventions are investigated during this phase. As a result, the ideal strategy for postpartum lifestyle intervention remains uncertain. In addition, the follow-up of postpartum interventions is often rather short. Thirdly, blended lifestyle interventions are to a limited extent investigated in the postpartum context. Fourthly, few studies previously reported phase angle values in the postpartum period. The existing studies on postpartum phase angle values were mainly limited to low- and middle-income countries, which may provide different reference values than in high-income countries. Lastly, women with a history of excessive GWG are currently neglected in research efforts, even though these women are at increased risk of long-term health consequences. The evolution of postpartum weight and body composition in this high-risk group is currently unknown, even though it can have important implications for long-term adverse health outcomes. Neither have previous lifestyle interventions targeted this high-risk group, and it remains therefore uncertain how these women can effectively be targeted for weight management. Promoting a healthy lifestyle and reducing weight retention in the postpartum period is a potentially important first step in the reduction of long-term obesity and adverse health outcomes.

The aim of the current thesis is therefore to investigate lifestyle behaviors (energy intake, eating behavior, physical activity and sedentary behavior), weight and body composition up to one year postpartum after a pregnancy with excessive GWG, and the effect of a lifestyle intervention on these factors. Objectives of the current thesis are outlined below. Data from the INTER-ACT randomized controlled trial is used to address objective two, three and four. In brief, the INTER-ACT study was a blended lifestyle intervention targeting women in the postpartum period after a pregnancy with excessive GWG. More details on the INTER-ACT study can be found in the appendix of this chapter and in the published study protocol [127].

The first objective was to compile evidence from the current scientific literature on the associations between several types of eating behaviors on the one hand, and GWG and PPWR on the other hand. To this end, **Chapter 2** describes a systematic review on the pre-existing literature on these associations.

The second objective was to provide insight into the role of lifestyle behaviors (energy intake, eating behavior, physical activity and sedentary behavior) on the spontaneous evolution of postpartum weight and body composition in postpartum after a pregnancy with excessive gestational weight gain. This objective is addressed in **Chapter 3** by describing the results of mixed model analyses of the INTER-ACT control group data. The chapter describes how weight and body composition evolve in the postpartum period in the absence of an intervention. The factors, including lifestyle behaviors, that play a role in this evolution in women with a history of excessive GWG are elaborated on.

The third objective was to explore the spontaneous evolution of phase angle during the first year postpartum after a pregnancy excessive GWG, and to investigate associations with potential explanatory factors. **Chapter 4** describes phase angle values in a population of postpartum women with a history of excessive GWG at three time points in the first year postpartum, based on data from the INTER-ACT control group. It is furthermore reported which socio-demographic, anthropometric, and lifestyle factors were associated with the phase angle values in this population.

The fourth objective was to examine the effects of a blended postpartum lifestyle intervention on lifestyle behaviors, postpartum weight retention and body composition after a pregnancy with excessive GWG. **Chapter 5** describes whether the postpartum phase of the INTER-ACT blended lifestyle intervention effectively improves lifestyle behaviors including energy intake, eating behavior, physical activity and sedentary behavior among women with a history of excessive GWG. Additionally, it is outlined whether these effects are maintained six months after the end of the postpartum intervention. **Chapter 6** describes whether the postpartum phase of the INTER-ACT blended lifestyle intervention is effective in the reduction of PPWR and improvement of body composition measures in women with a history of excessive GWG. Furthermore it is outlined whether improving lifestyle behaviors during the course of the intervention was associated with weight loss and improved body composition measures.

Chapter 7 discusses these findings of this study in a broader context. The chapter furthermore provides recommendations for future research as well as implications for clinical practice.

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Appendix: The INTER-ACT study

In chapter 3, 4, 5 and 6, data from the INTER-ACT study (INTERpregnAncy Coaching for a healthy fuTure) are used to address the objectives of this thesis. The INTER-ACT study provided a lifestyle intervention in the inter-pregnancy phase following a pregnancy with excessive GWG. Thereafter, the study continued in the subsequent pregnancy, but this part is not subject of the current thesis (Figure 1.3). The main goal of the INTER-ACT study was to reduce the prevalence of gestational diabetes, pregnancy-induced hypertension, caesarian section and large for gestational age infants in the next pregnancy. Sessions with a trained lifestyle coach took place at 6 weeks, 8 weeks, 12 weeks and 6 months postpartum. Subsequently, pregnancy sessions took place before the 15th week of pregnancy, at 20 weeks and at 32 weeks of pregnancy. The coaching sessions focused on healthy eating, physical activity, and mental well-being. In addition to the coaching sessions, intervention participants have access to a smartphone application. The INTER-ACT smartphone application sends motivating messages to support lifestyle change and facilitates self-monitoring of weight and physical activity with the use of a Bluetooth-connected weighing scale and activity tracker. The development process of the application is previously described in detail [128]. More information on the INTER-ACT study is provided in the published study protocol [127].

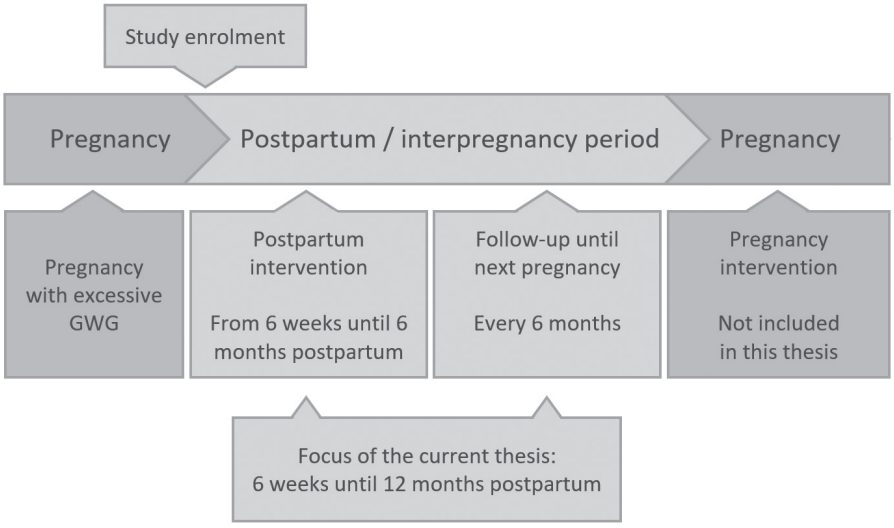

Figure 1.4. Timeline of the INTER-ACT study



CHAPTER 2.

Eating behaviors in relation to gestational weight gain and postpartum weight retention

A systematic review

Bijlholt, M., Van Uytsel, H., Ameye, L., Devlieger, R., & Bogaerts, A. (2020). *Obesity Reviews*, *21*(10), e13047.

Abstract

Preventing obesity is of utmost public health importance. This paper systematically reviews associations between eating behaviors and peripartum weight change. This knowledge is crucial in the development of interventions that reduce long-term obesity, often triggered and boosted in the peripartum. Through MEDLINE, EMBASE, and Web of Science, we identified 20 studies that fulfilled inclusion criteria: studies on food cravings, disinhibition, restrained, external, emotional, uncontrolled, intuitive, or mindful eating in relation to gestational or postpartum weight among adult women. Higher gestational weight gain was associated with lower intuitive eating (in 3/3 studies) and higher restrained eating (in 4/11 studies), external eating (in 2/2 studies), emotional eating (in 3/4 studies), food cravings (in 3/3 studies), and disinhibition (in 1/3 studies). No association with uncontrolled eating was found (in one study). No studies on mindful eating and gestational weight were identified. Higher postpartum weight loss was associated with higher restrained (in 2/4 studies) and intuitive eating (in 1/1 study). No associations between postpartum weight and food cravings, disinhibition, and mindful eating were found. No studies on external, emotional and uncontrolled eating, and postpartum weight were identified. Concluding, certain eating behaviors might be related to peripartum weight change.

Introduction

Obesity is a major public health threat as it is a risk factor for chronic diseases such as Type 2 diabetes, cardiovascular disease, and certain types of cancer.[1] Women of reproductive age are especially at risk of developing or worsening obesity, as pregnancy is usually accompanied by weight gain.[2] The Institute of Medicine (IOM) revised the guidelines for gestational weight gain (GWG) in 2009.[3] Globally, 47% of pregnant women exceed the recommended GWG,[4] which increases the risk of pregnancy- and birth- related complications such as pregnancy-induced hypertension, cesarean section, large for gestational age infants, and postpartum weight retention (PPWR).[3,4] PPWR is a serious public health concern because it contributes to the obesity epidemic.[2] Additionally, PPWR incurs an increased risk for complications in subsequent pregnancies.[5,6] Moreover, it contributes to an increased risk of obesity in the offspring, causing an intergenerational cycle of obesity.[7]

Generally, interventions to reduce GWG and PPWR target changes in food intake, alongside physical activity.[8,9] However, Skouteris et al. emphasize in their systematic review that psychological factors should have a more prominent role in intervention strategies to effectively reduce excessive GWG.[8] It is thus essential to gain insight into underlying psychological mechanisms, such as eating behaviors. Whereas the concept of food intake reflects which foods are eaten and how much (e.g., collected via food frequency questionnaires or 24-h dietary recall methods), the concept of eating behavior rather depicts the mechanisms driving behavior of how and under which circumstances one tends to eat. To illustrate, individuals high in restrained eating strongly attempt to limit their food intake,[10] individuals high in emotional eating tend to overeat during negative mood,[11] and individuals high in external eating tend to eat when they see, smell, or taste food that they find appealing.[12] It has to be noted that eating behaviors are normal characteristics that are (to a varying extent) present in every individual, which is distinct from eating disorders (e.g., anorexia nervosa) that are serious mental illnesses.[13]

It is essential to create an overview of which eating behaviors are related to GWG and PPWR and which are not, in order to gain knowledge of which eating behaviors are important to target in future public health efforts. Based on previous research, it is likely that eating behaviors are associated with GWG and PPWR. A systematic review by Kapadia and colleagues showed that restrained eating is a risk factor for excessive GWG, but this review did not address GWG in its totality.[14] Furthermore, the relationships between other types of eating behaviors and GWG were not reviewed. We expect that

not only restrained eating but also other types of eating behaviors play an important role in GWG and potentially also in PPWR. Studies among general populations clearly show that higher levels of eating behaviors such as emotional, external, and disinhibited eating are associated with higher body mass index (BMI) and weight gain.[12,15] This, together with the well-known pregnancy-related phenomena of intense emotions, stronger perception of external stimuli, and food cravings,[16] supports the hypothesis that the related eating behaviors also play an important role in GWG. Since GWG and PPWR are strongly related to each other, it is important to include not only GWG but also PPWR to gain insight in the role of eating behaviors in weight change in the peripartum as a continuous timeframe. Weight changes throughout the peripartum are essential determinants of health of both women and offspring.[7,17] Given the fact that eating behaviors are modifiable,[18–20] a better understanding of the relations between eating behaviors and peripartum weight changes could demonstrate which eating behaviors to target in lifestyle interventions to achieve an adequate GWG and prevent PPWR. This is of great public health importance, since it could prevent or reduce obesity in the longer term. The aim of this review was therefore to provide insight into the associations between eating behaviors and GWG and PPWR.

Methods

This systematic review was performed in accordance with the PRISMA guidelines.[21]

Definitions

Several types of eating behaviors have been distinguished in literature. Restrained eating is defined as "conscious restriction of food intake in order to control body weight or to promote weight loss."[10] External eating is defined as "eating in response to food stimuli such as sight, smell and taste of attractive food regardless of internal feelings of hunger and satiety."[12] Emotional eating is defined as "eating in response to negative emotions such as depressive feelings".[12] Food cravings are defined as "intense desires for particular types of food that are difficult to resist."[22] Disinhibition is defined as "the loss of control over eating behaviors in response to either internal or external cues."[23] Uncontrolled eating is defined as "tendency to overeat while experiencing feelings of being out of control."[24] Intuitive eating is the unconditional permission to eat, which relies on internal hunger and satiety cues and eating for physical rather than emotional reasons.[25] Mindful eating is defined as "a nonjudgmental awareness of physical and emotional sensations while eating or in a food-related environment."[26]

Gestational weight gain (GWG) is the amount of weight a woman gains during pregnancy. It is usually calculated by subtracting either the prepregnancy weight or the weight at the antenatal booking appointment from the last known weight in pregnancy. The IOM has formulated the following guidelines on recommended GWG: 12.5–18 kg for women with a prepregnancy BMI <18.5 kg/m^2; 11.5–16 kg for women with a prepregnancy BMI of 18.5–24.9 kg/m^2; 7–11.5 kg for women with a prepregnancy BMI of 25–29.9 kg/m^2; 5–9 kg for women with a prepregnancy BMI ≥30 kg/m^2.[17]

Postpartum weight retention (PPWR) is the amount of weight a woman retains after delivery. It is calculated by subtracting the prepregnancy weight from the weight at a certain time in the postpartum. As is regularly done in literature,[27,28] we allow a scope of 1 year after delivery, representing the long-term postpartum.

Eligibility criteria

Studies were eligible for this review if they assessed associations between eating behavior (i.e., restrained eating, external eating, emotional eating, food cravings, disinhibition, uncontrolled eating, intuitive eating, or mindful eating as defined above) and weight among adult pregnant or postpartum (until 1 year after delivery) women. Exclusion criteria were as follows: studies describing food intake (i.e., quantities of foods eaten or the nutrients derived from that) rather than eating behavior; studies among adolescent women, men, children, or animals; studies performed after bariatric surgery; qualitative studies; review articles; conference abstracts; studies not available in English. Studies assessing eating disorders (e.g., anorexia nervosa, bulimia nervosa, pica, and binge eating) were excluded, as these are serious mental illnesses that are outside the scope of this review. Intervention studies were not excluded provided that they reported associations between eating behavior and weight and met all other eligibility criteria. When two papers reported the same data from the same study sample, the study with the most comprehensive outcome data was included. We did not limit the search to a certain year of publication.

Search strategy

Literature searches were conducted in April 2019 and updated in March 2020 using MEDLINE (via PubMed), EMBASE, and Web of Science databases. Search terms (Supplementary Table 2.1) were developed with assistance of an experienced librarian. Synonyms and spelling variants to the concepts of “pregnancy,” “postpartum,” “eating behavior,” and “weight” were used

as search terms. The concept eating behavior also included the names of eating behavior questionnaires as search terms (e.g., Three-Factor Eating Questionnaire) as well as specific types of eating behaviors (e.g., restrained eating). No restriction on year of publication was applied. MeSH terms and Boolean operators were used and the search string was subsequently adapted to EMBASE and Web of Science formats.

Study selection

Duplicates were removed. Two reviewers (M. B. and H. V. U.) independently conducted a first screening round of titles and abstracts, and a second screening round of full text articles. Their selections of articles were compared after each screening round and consensus was achieved by discussion.

Data extraction and synthesis

Two reviewers (M. B. and H. V. U.) independently extracted data from the selected studies. A data extraction form was used to enter data on study design, specifications of participants, sample size, eating behavior measures, weight measures, and relevant outcomes. Consensus between the two researchers was achieved by discussion. The data were qualitatively synthesized by weight (GWG or PPWR) and type of eating behavior.

Quality appraisal

The quality of the final selection of studies was assessed using the NIH Study Quality Assessment Tools.[29] Since studies with different designs were included in this review, different variants of the tool were applied: for observational cohort and cross-sectional studies, for controlled intervention studies and for before–after studies without control group. Up to 14 questions were answered with yes, no, cannot determine, not reported, or not applicable. These comprise questions on study population, eligibility criteria, timeframe, objectivity of measurements, blinding, and statistical analyses, among others. Supplementary Table 2.1 provides the full list of quality assessment items. The quality assessment was conducted independently by two reviewers (M. B. and H. V.U.) after which they compared their findings and came to consensus by discussion.

Results

The literature search resulted in 802 articles, of which 361 duplicates were removed. Based on title and abstract screening, 364 articles were found ineligible: 174 did not assess eating behavior, 109 reported outcomes in

children, 33 were animal studies, 29 were not conducted during pregnancy or first year postpartum, eight were qualitative studies, seven specifically studied adolescent mothers, three were study protocols, and one was a systematic review. Additional 57 articles were found ineligible during full-text screening: 19 did not report weight outcomes, 16 did not investigate eating behavior, 12 were conference abstracts, three studied eating behavior and weight, but did not report associations between them, two were not conducted during pregnancy or first year postpartum, two were study protocols, and one was not full-text available in English. Furthermore, two studies were excluded because their results were already presented in other articles; the study that presented the most comprehensive outcome data was included in this review (Laraia et al.[50] was excluded, data presented by Mumford et al.[51]; Orloff et al.[52] was excluded, data presented by Blau et al.[43]). One study allowed women ≥16 to participate in their study, however they did not primarily focus on adolescent women, and only a small minority of participants were underage (5% was <20 years).[51] Therefore, this study was not excluded from this review. Twenty studies were eligible for further analysis (Figure 2.1).

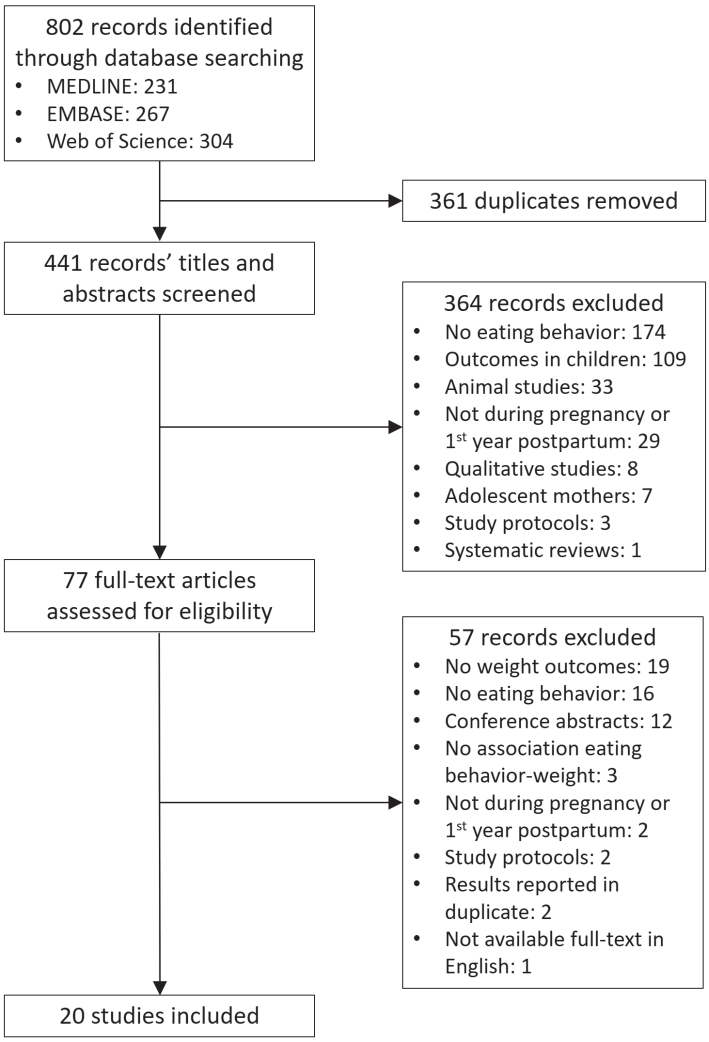

Figure 2.1. Flow diagram of study selection

Various questionnaires to determine eating behavior were used across studies. Some studies only used subscales of questionnaires or combined questionnaires. The used tools per study along with other study characteristics are listed in Table 2.1 (for studies on GWG) and Table 2.2 (for studies on PPWR). The original Three-Factor Eating Questionnaire (TFEQ) has subscales on dietary restraint, disinhibition, and hunger[53] and was used either fully or partially by eight studies.[33,37,39–42,44,45] The revised 18-item TFEQ (TFEQ-R18) consists of subscales on cognitive restraint, uncontrolled eating,

and emotional eating[11] and was used by one study.[38] The Dutch Eating Behavior Questionnaire (DEBQ) comprises restrained eating, emotional eating, and external eating subscales[49] and was fully or partially used by three studies.[42,43,47] The Revised Restraint Scale (RRS) was used by three studies that adapted the wordings of the questionnaire in order to inquire retrospectively about restrained eating prior to pregnancy.[46,51,54] The Food Craving Inventory[31] was used by two studies.[39,43] Two studies[32,48] used the Intuitive Eating Scale-2,[55] and two studies[35,56] used the Intuitive Eating Scale for Pregnancy.[36] The Weight and Lifestyle Inventory with questions on food cravings,[57] the Mindful Eating Questionnaire,[26] and the Eating Stimulus Index with a dietary restraint subscale[30] were used by one study each.[34,37,39] Two studies administered questions on food cravings that did not belong to an existing questionnaire.[42,58] Supplementary Tables 2.3 and 2.4 show overviews of baseline BMI, data collection time points, and method of weight recording for each study.

Quality

Five out of 20 studies had a good quality (>75% of quality criteria met), 10 had a fair quality (50%–75% of quality criteria met), and five studies had a poor quality (<50% of quality criteria met) (Table 2.3). A major issue was the use of self-reported weight. Fourteen out of 20 studies used self-reported prepregnancy weight, and some also used self-reported pregnancy weight.[42,43,46] Using self-reported prepregnancy weight might introduce considerable bias in the study findings, since prepregnancy weight is used to calculate both the prepregnancy BMI, on which IOM guidelines for recommended GWG are based, as well as GWG. Only three studies measured baseline weight[35,39,41] and three studies retrieved weight from the medical record,[38,48,58] although two of the latter used self-reported weight in case no measured weight was available in the medical record.[38,48] A disadvantage of using the weight from the medical record is that measurement took place during the antenatal booking visit, which usually takes place between 6 to 12 weeks of gestational age. Measured baseline weight is usually also taken in the first weeks of pregnancy rather than prepregnancy. Weight gain of the first weeks of pregnancy is in that case not taken into account. Supplementary Tables 2.3 and 2.4 provide overviews of the method of weight recording for each study. Another quality concern among the cross-sectional and cohort studies was that the exposure (eating behavior) was measured only once. Only six studies repeated measurement of eating behavior during the study period.[32,35,39,40,47,48] Neither of the RCT's had blinded participants and providers to treatment group assignment, but this was not possible due to the nature of a lifestyle intervention.[44,45] Six studies did not

use validated questionnaires, or changed the wordings of questionnaires, which could therefore no longer be regarded as validated.[37,42,46,51,54,58] In one study, participants were not representative of the target population, since all participants had overweight or obesity, whereas this was not specifically the target population of the study.[34]

Eating behavior and gestational weight gain

Table 2.1 presents the study outcomes regarding the associations between eating behaviors and GWG.

Restrained eating

GWG and restrained eating were studied by 11 of the included papers. Four of these showed associations between higher restrained eating and increased GWG;[33,46,51,54] the remaining seven studies did not find associations.[37,38,40–43,47] Mumford et al. used the Revised Restraint Scale (RRS) and divided their sample in restrained and nonrestrained eating based on the median of RRS scores. They found that women high in restrained eating with normal weight, overweight, and obesity had on average a 2.2 kg higher GWG compared to women low in restrained eating of the same BMI groups (significant for normal weight, $p < .001$, and obesity, $p = .03$).[51] Heery et al. likewise used the RRS and similarly found that women high in restrained eating had a higher GWG (+0.8 kg) than those low in restrained eating. After adjustment for several covariates including prepregnancy BMI, restrained eating remained associated with GWG ($B = 1.49$, 95% CI [0.70, 2.29], $p < .001$). Furthermore, it was found that women high in restrained eating in comparison with women low in restrained eating were more likely to have an excessive GWG (67.6% vs. 57.5%, $p < .05$), although the associations were not significant after adjustment for parity, nationality, BMI category, height, and depressive symptoms.[54] Conway et al. similarly used the RRS, but did not find an association between restrained eating and total GWG (based on self-reported weights). They did, however, find that women high in restrained eating were significantly less likely to achieve an adequate GWG based on 1990 IOM guidelines compared to women low in restrained eating ($p = .026$); their weight gain was more often either above or below the recommendations.[46] The study of Slane et al. among pregnant women who quit smoking showed that higher restrained eating was associated with greater total GWG regardless of prepregnancy BMI and other covariates ($B = 1.4$, SE 0.58, $p = .02$).[33] Seven studies did not find associations between restrained eating and GWG. Detailed information on study design, sample size, questionnaires used, and outcomes can be found in Table 2.1.

Table 2.1. Characteristics and outcomes of included studies on eating behavior and gestational weight gain

Author (year)	Design	Participants	Sample size	Eating behavior measure	Outcomes
Restrained eating (RE)					
Plante et al. (2020)[40]	Prospective	Pregnant women	53	TFEQ	No significant association between RE and adequacy of GWG.
Tang et al. (2020)[41]	Prospective	Women in their 2nd pregnancy	190	TFEQ	No significant association between RE and likelihood of EGWG (unadjusted: OR = 1.05, 95% CI [0.99, 1.11]; adjusted for BMI category: OR = 1.02, 95% CI [0.96, 1.09]; adjusted for BMI category and sociodemographics: OR = 1.02, 95% CI [0.96, 1.09]).
Garduño-Alanis et al. (2019)[38]	Cross-sectional	Primigravid women with T2DM or GDM	57	TFEQ-R18	No significant association between RE and GWG (p = .6).
Blau et al. (2018)[43]	Cross-sectional	Pregnant women	113	DEBQ	No significant association between RE and EGWG (r = 0.16).
Heery et al. (2016)[54]	Prospective and retrospective	Pregnant women	799	RRS	Higher GWG among RE compared to non-RE (mean GWG 16.3 kg and 15.5 kg, respectively, p < .05). Higher GWG among RE compared to non-RE after adjustment for parity, nationality, pre-pregnancy BMI, height, depressive symptoms, health insurance, GA, and time since last measurement until delivery (B = 1.49, 95% CI [0.70, 2.29], p < .001). More frequent EGWG among RE compared to non-RE (67.6% and 57.5%, respectively, p < .05). No significant association between RE and EGWG after adjustment for parity, nationality, BMI, height and depressive symptoms (B = 1.28, 95% CI [0.92, 1.78], p = .147).
Slane & Levine (2015)[33]	Cross-sectional	Pregnant women who quit smoking as a result of pregnancy, GA ≥28 weeks	248	TFEQ	Higher RE scores associated with higher GWG, also after controlling for pre-pregnancy BMI, weeks to delivery, age, race, and nicotine dependence (B = 1.4, SE 0.58, p = .02). No significant association between RE and adequacy of GWG.

Author (year)	Design	Participants	Sample size	Eating behavior measure	Outcomes
Van der Wijden et al. (2014)[47]	Prospective	Pregnant women, GA 15 and 35 weeks	161	DEBQ	No significant association between RE and GWG.
Allison et al. (2012)[37]	Cross-sectional	Pregnant African American women; GA 14-24 weeks; pregravid BMI ≥ 25	120	TFEQ-RE	No significant association between RE and GWG (r = -0.023).
Mumford et al. (2008)[51]	Prospective and retrospective	Pregnant women, mean GA 14 weeks	1223	RRS	Higher GWG among RE compared to non-RE with normal weight (+2.5 kg, p < .001), overweight (+1.59 kg, p = .168), and obesity (+1.93 kg, p = .03).
Clark & Ogden (1999)[42]	Cross-sectional and retrospective	Primigravid women, GA 24-28 weeks	50	DEBQ-RE	No significant association between RE and GWG (mean GWG RE: 8.69 kg ± 4.91; non-RE: 8.16 kg ± 3.95).
Conway et al. (1999)[46]	Prospective and retrospective	Pregnant Caucasian women, from GA ~12 weeks	62	RRS	Less frequent adequate GWG among RE compared to non-RE (data not shown, p = .026). No significant difference in GWG between RE-groups (mean GWG RE: 15.2 kg ± 4.87; non-RE: 16.2 kg ± 4.01, p = .42).
External eating (EX)					
Blau et al. (2018)[43]	Cross-sectional	Pregnant women	113	DEBQ	Higher EX scores associated with more frequent EGWG (r = 0.21, p < .05).
Van der Wijden et al. (2014)[47]	Prospective	Pregnant women, GA 15 and 35 weeks	161	DEBQ	Higher GWG associated with higher EX scores at 15 weeks of gestation (beta = 1.39, 95% CI [0.08, 2.71], p = .04) and 35 weeks of gestation (beta = 1.39, 95% CI [0.04, 2.74], p = .04) adjusted for BMI, age, and time between measurements. No significant association between EX and GWG with EE and RE in the model (at 15 weeks GA: beta = 1.41, 95% CI [-0.12, 2.94]; at 35 weeks GA: beta = 0.96, 95% CI [-0.53, 2.45]). No significant difference in GWG between women with EX (11.4 kg ± 4.0), RE (10.8 kg ± 2.8), and EM (13.8 kg ± 4.1).

Author (year)	Design	Participants	Sample size	Eating behavior measure	Outcomes
Emotional eating (EM)					
Garduño-Alanis et al. (2019)[38]	Cross-sectional	Primigravid women with T2DM or GDM	57	TFEQ-R18	Higher EM scores (range 3-12) associated with higher GWG among women with normal pre-pregnancy BMI (adjusted for age, beta = 2.8, 95% CI [1.2, 4.4], p = .003). No significant association between GWG and EM among women with overweight (p = .3) and obesity (p = .6).
Blau et al. (2018)[43]	Cross-sectional	Pregnant women	113	DEBQ	Higher EM scores associated with more frequent EGWG (r = 0.31, p < .01).
Van der Wijden et al. (2014)[47]	Prospective	Pregnant women, GA 15 and 35 weeks	161	DEBQ	Higher GWG among EM compared to RE (13.8 kg ± 4.1 and 10.8 kg ± 2.8, respectively, p < .05). Higher GWG associated with higher EM scores at 35 weeks of pregnancy and GWG (beta = 0.97, 95% CI [0.06, 1.89], p = .04) adjusted for BMI, age, and time between measurements, without RE and EX in the model. No significant association between GWG and EM together with RE and EX in the model.
Allison et al. (2012)[37]	Cross-sectional	Pregnant African American women; GA 14-24 weeks; pregravid BMI ≥ 25	120	Weight and Lifestyle Inventory	No significant associations between perceived contribution of eating when anxious, tired, bored, stressed, angry, depressed, or alone on GWG, and actual GWG.
Food cravings (FC)					
Blau et al. (2018)[43]	Cross-sectional	Pregnant women	113	FCI	More frequent EGWG associated with FC for high fat foods (r = 0.4, p ≤ .001) and FC for fast foods (r = 0.23, p < .05). No significant associations between EGWG and FC for sweets (r = 0.15), or cravings for carbohydrates/starches (r = 0.08).
Hill et al. (2016)[58]	Prospective	Pregnant women, GA ~29 weeks	1639	Self-designed questions	Higher GWG associated with FC (p = .043) (author contacted, no further data available). No significant difference in weekly rate of GWG between having FC and not having FC.

Author (year)	Design	Participants	Sample size	Eating behavior measure	Outcomes
Allison et al. (2012)[37]	Cross-sectional	Pregnant African American women; GA 14-24 weeks; pregravid BMI ≥ 25	120	Weight and Lifestyle Inventory	Perceived contribution of FC to GWG was significantly associated with actual GWG (r = 0.21, p < 0.05). Controlling for maternal age, gestational age, pre-pregnancy BMI and education, eating due to cravings was predictive of GWG (adjusted beta = 5.1 kg, 95% CI [1.2, 8.9], p = .01). Same prediction after adding parity to the model. Adding smoking status: adjusted beta = 4.7 kg, 95% CI [0.6, 8.7], p = .026.
Disinhibition (DI)					
Plante et al. (2020)[40]	Prospective	Pregnant women	53	TFEQ	No significant association between DI and adequacy of GWG.
Tang et al. (2020)[41]	Prospective	Women in their 2nd pregnancy	190	TFEQ	Higher DI score associated with higher odds of EGWG (unadjusted OR = 1.17, 95% CI [1.05, 1.29]). Not significant when adjusted for baseline BMI category (OR = 1.09, 95% CI [0.97, 1.21]) or baseline BMI category and sociodemographics (OR = 1.09, 95% CI [0.97, 1.23]).
Slane & Levine (2015)[33]	Cross-sectional	Pregnant women who quit smoking as a result of pregnancy, GA ≥28 weeks	248	TFEQ	No significant association between DI and GWG. No significant association between DI and adequacy of GWG.
Uncontrolled eating (UE)					
Garduño-Alanis et al. (2019)[38]	Cross-sectional	Primigravid women with T2DM or GDM	57	TFEQ-R18	No significant association between UE and GWG.
Intuitive eating (IE)					

Author (year)	Design	Participants	Sample size	Eating behavior measure	Outcomes
Ledoux et al. (2020)[56]	Prospective and retrospective	Pregnant women	253	IES-P	Higher values IE subscale 'unconditional permission to eat' score associated with lower GWG in the total sample, adjusted for BMI (unstandardized beta = -2.31, standardized beta = -0.16, $p < .05$). Higher values IE subscale 'eating for physical rather than emotional reasons' score associated with lower GWG among subsample with obesity, adjusted for BMI (unstandardized beta = -5.92, standardized beta = -0.47, $p < .05$). No significant association between subscale 'reliance on internal hunger and satiety cues' and GWG. Overall IE explained 5% of the variance of GWG in the total sample, adjusted for BMI (adjusted $R^2 = 0.05$, $p < .01$) and 25% in participants with obesity (adjusted $R^2 = 0.25$, $p < .05$). IE no significant predictor of EGWG in the total sample ($p = .61$) or in BMI subsamples (under-/normal weight: $p = .94$; overweight: $p = .28$; obesity: $p = .31$).
Plante et al. (2019)[32]	Prospective	Pregnant women	74	IES-2	1st trimester: Higher IE score among women with adequate GWG (mean 3.9, SD 0.5) compared to EGWG (mean 3.6, SD 0.6, $p = .04$) adjusted for pre-pregnancy BMI. Higher subscale score 'eating for physical rather than emotional reasons' among women with adequate GWG (mean 4.2, SD 0.7) compared to EGWG (mean 3.6, SD 0.9, $p = .03$) adjusted for pre-pregnancy BMI. 2nd trimester: No significant association between IE and adequacy of GWG adjusted for pre-pregnancy BMI. 3rd trimester: Higher subscale score 'eating for physical rather than emotional reasons' among women with adequate GWG (mean 4.2, SD 0.7) compared to EGWG (mean 3.5, SD 0.7, $p = .02$) adjusted for pre-pregnancy BMI.
Paterson et al. (2019)[35]	Prospective	Pregnant women	218	IES-P	Higher IE scores associated with decreased GWG (mean difference -1.3 kg, 95% CI [-2.5, -0.1] per point IE score), adjusted for ethnicity, parity, smoking, education, GA, and baseline BMI. No significant associations between GWG and IE subscales (unconditional permission to eat, eating for physical rather than emotional reasons, reliance on internal hunger and satiety cues).

Abbreviations: BMI = body mass index; DEBQ = Dutch Eating Behavior Questionnaire; DI= disinhibition; EGWG = excessive gestational weight gain; EM = emotional eating; EX = external eating; FC = food cravings; FCI = Food Craving Inventory; GA = gestational age; GDM = gestational diabetes mellitus; GA = gestational age; GWG = gestational weight gain; IE = intuitive eating; IES-2 = intuitive eating scale-2; IES-P = intuitive eating scale for pregnant women; IOM = Institute of Medicine; RCT = randomized controlled trial; RE = restrained eating; RRS = Revised Restraint Scale; T2DM = type 2 diabetes mellitus; TFEQ(-R18) = Three Factor Eating Questionnaire (revised 18-item version); UE = uncontrolled eating

Table 2.2. Characteristics and outcomes of included studies on eating behavior and postpartum weight

Author (year)	Design	Participants	Sample size	Eating behavior measures	Outcomes
Restrained eating (RE)					
Most et al. (2020)[39]	Prospective	Women with 1st trimester BMI ≥30, 12 months postpartum	37	TFEQ	No significant association between RE and PPWL.
Phelan et al. (2019)[44]	Follow-up of RCT in pregnancy (no postpartum intervention)	Women 6 and 12 months postpartum with pre-pregnancy BMI >25	257 (128 enhanced usual care; 129 intervention)	TFEQ	Decreased RE from 35-36 weeks of pregnancy until 12 months postpartum associated with lower odds of returning to pre-pregnancy weight, equal for intervention and control group (OR = 0.92, 95% CI [0.85, 0.98], p = .02).
Phelan et al. (2014)[45]	Follow-up of RCT in pregnancy (no postpartum intervention)	Women 6 and 12 months postpartum	331 (167 standard care; 164 intervention)	TFEQ	No significant association between RE and PPWL.
Cahill et al. (2012)[34]	Non-randomized weight loss intervention	Low-income women with BMI ≥ 25; 0-4 months postpartum	58	Eating Stimulus Index	Greater increases of RE scores among women with higher PPWL (≥2.27 kg) compared to lower PPWL (<2.27 kg) (+2.2 ± 0.4 and +0.6 ± 0.4, respectively, range 3-15; p < .01). Controlled for GWG and BMI, regression of change in restrained eating scores from pre-study to post-study in predicting postpartum weight loss were significant (standardized beta = 0.34, adjusted R^2 = 0.20). GWG, infant feeding method and BMI explained 11.7% of the variance of PPWL. Addition of RE and total energy intake significantly improved the prediction model (p < .01): explained variance of 24.6% of PPWL.
Food cravings (FC)					
Most et al. (2020)[39]	Prospective	Women with 1st trimester BMI ≥30, 12 months postpartum	37	FCI	No significant association between FC and PPWL.
Disinhibition (DI)					
Most et al. (2020)[39]	Prospective	Women with 1st trimester BMI ≥30, 12 months postpartum	37	TFEQ	No significant association between DI and PPWL.

Author (year)	Design	Participants	Sample size	Eating behavior measures	Outcomes
Phelan et al. (2019)[44]	Follow-up of RCT in pregnancy (no postpartum intervention)	Women 6 and 12 months postpartum with pre-pregnancy BMI >25	257 (128 enhanced usual care; 129 intervention)	TFEQ	No significant association between DI and PPWL.
Phelan et al. (2014)[45]	Follow-up of RCT in pregnancy (no postpartum intervention)	Women 6 and 12 months postpartum	331 (167 standard care; 164 intervention)	TFEQ	No significant association between DI and PPWL.
Intuitive eating (IE)					
Quansah et al. (2019)[48]	Prospective	Women with GDM in the preceding pregnancy, 12 months postpartum	117	IES-2	Higher postpartum IE scores associated with decreased PPWR, adjusted for age and GA at first GDM visit ('eating for physical rather than emotional reasons' subscale: *B* =-0.230, 95% CI [-2.976, -0.370], *p* = .012; 'reliance on hunger and satiety cues' subscale: *B* = -0.193, 95% CI [-2.847, -0.083], *p* = .037). Among overweight and obese subgroup: higher postpartum IE scores associated with decreased PPWR, adjusted for age and GA at first GDM visit ('eating for physical rather than emotional reasons' subscale: *B* = -0.347, 95% CI [-5.152, -0.562], *p* = .009; 'reliance on hunger and satiety cues' subscale: *B* = -0.405, 95% CI [-6.529, -1.494], *p* = .002). No significant association between postpartum IE and PPWR among normal weight women. No significant association between IE measured during pregnancy and PPWR.
Mindful eating (ME)					
Most et al. (2020)[39]	Prospective	Women with 1st trimester BMI ≥30, 12 months postpartum	37	MEQ	No significant association between ME and PPWL.

Abbreviations: BMI = body mass index; DI= disinhibition; FC = food cravings; FCI = food craving inventory; GA = gestational age; GDM = gestational diabetes mellitus; GWG = gestational weight gain; IE = intuitive eating; IES-2 = intuitive eating scale-2; ME = mindful eating; MEQ = mindful eating questionnaire; PPWL = postpartum weight loss; PPWR = postpartum weight retention; RCT = randomized controlled trial; RE = restrained eating; TFEQ = Three Factor Eating Questionnaire

Table 2.3. Quality assessment

Quality assessment of observational cohort and cross-sectional studies [a]														
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**
Ledoux et al. (2020)[56]	✓	✓	NR	✓	✓	✓	✓	✓	✓	✗	✗	✓	✓	✓
Most et al. (2020)[39]	✓	✗	NR	NR	✗	✓	✓	✓	✓	✓	✓	NR	NR	✓
Plante et al. (2020)[40]	✓	✓	NR	✓	✗	✗	✓	✓	✓	✓	✗	NR	✗	✗
Garduño-Alanis et al. (2019)[38]	✓	✓	✓	✓	✗	✗	✓	✓	✓	✗	✓	✓	✓	✓
Paterson et al. (2019)[35]	✓	✓	✗	✓	✗	✗	✓	✓	✓	✓	✓	✗	✓	✓
Plante et al. (2019)[32]	✓	✓	NR	✓	✗	✗	✓	✓	✓	✓	✗	NR	✓	✗
Quansah et al. (2019)[48]	✓	✓	NR	✓	✗	✓	✓	✓	✓	✓	✗	NR	✗	✓
Blau et al. (2018)[43]	✓	✗	NR	✗	✓	✗	✓	✓	✓	✗	✗	NA	NR	✗
Heery et al. (2016)[54]	✓	✓	✓	✓	✓	✓	✓	✗	✗	✗	✗	NR	✓	✓
Hill et al. (2016)[58]	✓	✓	NR	✓	✗	✗	✓	✗	✗	✗	✓	NR	NR	✓
Slane et al. (2015)[33]	✓	✗	CD	✗	✗	✗	✓	✓	✓	✗	✗	NR	NR	✓
Van der Wijden et al. (2014)[47]	✓	✓	NR	✓	✗	✓	✓	✓	✓	✓	✗	✗	✓	✓
Allison et al. (2012)[37]	✓	✗	✓	✓	✗	✓	✓	✓	✗	✗	✗	NR	✓	✓
Mumford et al. (2008)[51]	✓	✓	✓	✓	✗	✓	✓	✗	✗	✗	✗	NR	✓	✓
Clark et al. (1999)[42]	✓	✗	✓	✓	✗	✓	✓	✗	✗	✗	✗	NA	✓	✗
Conway et al. (1999)[46]	✓	✓	✓	✓	✗	✓	✓	✗	✗	✗	✗	NR	✓	✗
Quality assessment of controlled intervention studies [b]														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Phelan et al. (2019)[44]	✓	✓	✓	✗	✓	✓	✗	✓	CD	✓	✓	✓	✓	✓
Phelan et al. (2014)[45]	✓	✓	✓	✗	✓	✓	✗	✓	CD	✓	✓	✓	✓	✓

Quality assessment of before-after studies with no control group [c]												
	1	2	3	4	5	6	7	8	9	10	11	12
Tang et al. (2020)[41]	✓	✓	✗	✓	✓	✓	✓	NR	✓	✓	✓	NA
Cahill et al. (2012)[34]	✓	✓	✗	✓	✗	✓	✓	NR	✓	✓	✗	NA

NA = Not Applicable, NR = Not Reported, CD = Cannot Determine

[a] Items of the NIH quality tool for observational cohort and cross-sectional studies: 1=research question; 2=study population; 3=participation rate; 4=recruitment; 5=sample size; 6=exposure prior to outcome measurement; 7=timeframe; 8=levels of exposure 9=reliability of exposure measures; 10=repeated exposure assessment; 11=reliability of outcome measures; 12=blinding; 13=follow-up rate; 14=statistical analyses.

[b] Items of the NIH quality tool for controlled intervention studies: 1=described as randomized; 2=method of randomization; 3=concealment of randomization; 4=blinding of participants and providers; 5=blinding of assessors; 6=similarity of groups at baseline; 7=drop-out; 8=differential drop-out between groups; 9=adherence; 10=other interventions avoided; 11=reliability of outcome measures; 12=sample size; 13=prespecified outcomes; 14=intention-to-treat analysis.

[c] Items of the NIH quality tool for before-after studies with no control group: 1=research question; 2=eligibility criteria; 3=representativeness of study population; 4=all eligible participants enrolled; 5=sample size; 6=clear intervention description; 7=reliability of outcome measures; 8=blinding of assessors; 9=follow-up rate; 10=statistical analysis; 11=multiple outcome measures; 12=group-level interventions and individual-level outcome efforts (full description in Supplementary Table 2.2).

External eating

Both Blau et al.[43] and Van der Wijden et al.[47] used the DEBQ to assess external eating and correlations with GWG. Blau et al. found that higher values of external eating resulted more often in excessive GWG based on self-reported weights (r = 0.21, p < .05). Prepregnancy BMI was not accounted for.[43] Van der Wijden et al. found associations between higher external eating scores at 15 and 35 weeks of pregnancy and higher GWG (at 15 weeks: beta = 1.39, 95% CI [0.08, 2.71], p = .04; at 35 weeks: beta = 1.39, 95% CI [0.04, 2.74], p = .04) adjusted for BMI, age, and time between measurements, without correction for restrained and emotional eating. However, when all three eating styles concurrently were tested, no significant evidence for an association with GWG was found.[47]

Emotional eating

Four studies examined emotional eating[37,38,43,47] of which three found associations between greater emotional eating and increased GWG. Garduño-Alanis et al. found in their study of women with Type 2 or gestational diabetes that more emotional eating was associated with higher GWG among women

with a normal prepregnancy BMI (adjusted for age, beta = 2.8, 95% CI [1.2, 4.4], p = .003), but not among women with overweight and obesity.[38] Blau et al. found that higher emotional eating scores were associated with more frequent excessive GWG based on self-reported weights (r = 0.31, p < .01), which was, however, mediated by frequency of cravings for high fat foods and not adjusted for prepregnancy BMI and other potential covariates.[43] Van der Wijden et al. showed a higher GWG among women with emotional eating behavior compared to women with restrained eating behavior (13.8 kg ± 4.1 and 10.8 kg ± 2.8, respectively, p < .05). Furthermore, higher emotional eating scores were associated with higher GWG at 35 weeks of pregnancy (beta = 0.97, 95% CI [0.06, 1.89], p = .04), adjusted for BMI, age, and time between measurements, without correction for restrained and external eating.[47] Allison et al. studied different emotional eating behaviors separately: eating when anxious, bored, stressed, angry, depressed, or alone. None of these emotional eating behaviors were significantly associated with GWG.[37]

Food cravings

Three studies reported results regarding the relationship between food cravings and GWG and all found that more food cravings were associated with higher GWG.[37,43,58] The study of Blau et al. was the only one to distinguish between cravings for different food groups. They reported associations between more frequent excessive GWG based on self-reported weights and higher scores of cravings for high fat foods (r = 0.4, p ≤ .001) as well as cravings for fast foods (r = 0.23, p < .05). Food cravings did not differ by prepregnancy BMI. As mentioned earlier, this study showed that cravings for high fat foods mediated the association between emotional eating and excessive GWG.[43] Allison et al. showed that among pregnant African American women with overweight, attributing GWG to food cravings was correlated with increased actual GWG (r = 0.21, p < .05). In a regression model with maternal age, gestational age, prepregnancy BMI, and education, eating due to cravings was predictive of GWG: every unit increase of eating due to cravings (range 1–5) led to adjusted beta 5.1 kg higher GWG (95% CI [1.2, 8.9], p = .01). Parity and smoking status only slightly changed the prediction (adjusted beta = 4.7 kg, 95% CI [0.6, 8.7], p = .026).[37] Hill et al. reported that a higher GWG was observed among women who had food cravings compared to women who did not have cravings during pregnancy (p = .043). Prepregnancy BMI was not accounted for.[58]

Disinhibition

Three studies investigated disinhibition and GWG,[33,40,41] of which one found that higher disinhibition scores were associated with higher odds of excessive GWG (based exclusively on measured weights) among women in their second pregnancy (unadjusted OR = 1.17, 95% CI [1.05, 1.29]). This was, however, no longer significant after adjustment for baseline BMI category and sociodemographic factors (OR = 1.09, 95% CI [0.97, 1.23]).[41] The two other studies did not find statistical evidence for an association between disinhibition and GWG.[33,40]

Uncontrolled eating

One study examined uncontrolled eating but did not find an association with GWG.[38]

Intuitive eating

Three studies investigated intuitive eating and all found significant associations with GWG. Paterson et al. showed that higher intuitive eating scores were associated with decreased total GWG (mean difference –1.3 kg per point intuitive eating score, 95% CI [–2.5, –0.1], adjusted for ethnicity, parity, smoking, education, GA, and baseline BMI).[35] Plante et al.[32] showed that in the first trimester of pregnancy specifically women with an adequate GWG for gestational age scored significantly higher on intuitive eating compared to those with an excessive GWG for gestational age (respectively mean 3.9, SD 0.5 and mean 3.6, SD 0.6, $p = 0.4$, adjusted for prepregnancy BMI).[32] In the study of Ledoux et al., the three intuitive eating subscales together explained 5% of the variance in GWG in the total sample, but 25% of the variance in GWG among women with obesity ($p < .05$). Intuitive eating could not predict excessive GWG.[56]

The subscale "eating for physical rather than emotional reasons" of the intuitive eating scale was shown to be associated with GWG in the studies of Ledoux et al.[56] and Plante et al.[32]. Higher scores on this subscale were associated with lower GWG among women with obesity (unstandardized beta = –5.92, standardized beta = –0.47, $p < .05$, adjusted for BMI).[56] In both the first and the third trimester, women with adequate GWG scored higher on this subscale compared to women with excessive GWG (adjusted for prepregnancy BMI).[32] A higher score on the subscale "unconditional permission to eat" was associated with lower GWG in one study (unstandardized beta = –2.31, standardized beta = –0.16, $p < .05$, adjusted for BMI).[56] None of the three studies found significant associations between the

subscale "reliance on internal hunger and satiety cues" and GWG. Plante et al. employed an expanded version of the intuitive eating scale with an additional subscale "body-food choice congruence," but did not find an association between this subscale and GWG.[32]

Eating behaviors not identified in literature

No studies were identified on the association between mindful eating and GWG.

Eating behavior and postpartum weight retention

Table 2.2 presents the study outcomes regarding the associations between eating behaviors and PPWR.

Restrained eating

Two of four studies on postpartum weight and restrained eating showed evidence for associations. Cahill et al. conducted an 8-week nonrandomized weight loss intervention in early postpartum (up to four months postpartum) among low-income women with overweight or obesity. Women with a higher postpartum weight loss (PPWL) (>2.27 kg cutoff) had a greater increase in restrained eating scores (+2.2 ± 0.4, range of restrained eating scale 3–15) compared to women with a less PPWL (<2.27 kg) (+0.6 ± 0.4, $p < .01$). Controlling for GWG and BMI, change of restrained eating scores over this period significantly predicted PPWL (standardized beta = 0.343, adjusted R^2 = 0.199, $p < .05$). These findings might be effects of the intervention; however, this could not be ascertained due to the absence of a control group.[34] Phelan et al. (2019) conducted a postpartum follow-up of a RCT that took place in pregnancy, which primarily aimed to limit GWG among women with prepregnancy BMI ≥ 25. The study showed that a decrease in restrained eating led to a lower odds of returning to prepregnancy weight at twelve months after delivery (OR = 0.92, 95% CI [0.85, 0.98], $p = .02$). This was not a long-term effect of the intervention, as there was no difference between intervention and control group. Prepregnancy BMI and GWG were not adjusted for.[44] Phelan et al. (2014) likewise conducted a postpartum follow-up of a pregnancy RCT that aimed to limit GWG. However, in this study, no relationship between PPWR and restrained eating was found at six and twelve months after delivery.[45] A cohort study among women with obesity by Most et al. did not find an association between PPWR and restrained eating at twelve months postpartum either.[39]

Food cravings

No significant association between food cravings and PPWR was found in a cohort of women with obesity.[39]

Disinhibition

No significant associations between disinhibition and PPWR were found.39,44,45

Intuitive eating

In one study, higher intuitive eating scores were shown to be associated with decreased PPWR (entirely based on measured weights) at 1 year postpartum among women who had had gestational diabetes mellitus. When stratified for BMI category, this association was found among those with overweight and obesity, but not among women with normal weight (total sample: adjusted for age and GA at first GDM (visit "eating for physical rather than emotional reasons" sub-scale: B = –0.230, 95% CI [–2.976, –0.370], p = .012; "reliance on hunger and satiety cues" subscale: B = –0.193, 95% CI [–2.847, –0.083], p = .037. Among overweight and obese subsample "eating for physical rather than emotional reasons" subscale: B = –0.347, 95% CI [–5.152, –0.562], p = .009; "reliance on hunger and satiety cues" subscale: B = –0.405, 95% CI [–6.529, –1.494], p = .002). Previous GWG was not adjusted for in these analyses.[48]

Mindful eating

No association was found between mindful eating and PPWR among women with obesity.[39]

Eating behaviors not identified in literature

No studies were identified on associations between PPWR and external eating, emotional eating, and uncontrolled eating.

Discussion

The current systematic review is novel in its approach of investigating associations between a range of eating behaviors and both GWG and PPWR. Restrained eating was the most often studied type of eating behavior in relation to GWG. Seven out of 11 identified studies did not find associations between restrained eating and GWG, of which two were of good quality, three of fair quality, and two of poor quality. The four studies that did find associations (three of fair quality, one of poor quality) demonstrated

associations between higher scores of restrained eating and a higher GWG. This is in line with findings from nonpregnant populations, where the majority of studies point towards associations between higher restrained eating scores and higher BMI.[12,59,60]

Although the findings provide limited evidence for an association between higher restrained eating and higher GWG, several explanations for a potential relationship can be suggested. Schaumberg et al.[61] indicated in their review focusing on nonpregnant populations that even though restrained eating entails a cognitive attempt to limit food intake, it might actually result in an increased intake, as periods of restrained eating are often alternated with periods of uncontrolled eating.[61] In such case, associations between GWG and uncontrolled eating or disinhibition, which are greatly overlapping concepts, would be expected. Only one study in this review, however, found an association between disinhibition and the likelihood of having excessive GWG, yet this study was of good quality. Contrastingly, three studies (of good, fair, and poor quality) could not establish any associations between disinhibited or uncontrolled eating and GWG. A second potential explanation is that restrained eating might be a reaction to weight gain rather than a risk factor for weight gain.[61] In the current review, however, such causal pathways could not be confirmed for pregnant populations. Thirdly, pregnancy might generate a shift from highly restrained eating prior to pregnancy towards unrestrained eating during pregnancy, as some women see pregnancy as an excuse to gain weight.[62,63] This perception might diminish the attempt to limit food intake for weight control typical for restrained eating. Some of the studies in the current review retrospectively determine restrained eating based on prepregnancy eating behaviors. This could result in biased conclusions if the presumed shift from restrained to nonrestrained eating indeed occurs. This might therefore explain the association between high restrained eating (prior to pregnancy) and increased GWG as found in seven of 11 studies in the current review. Remarkably, three out of four studies that found associations between restrained eating and GWG indeed used the Revised Restraint Scale, which retrospectively examines restrained eating prior to pregnancy.

Restrained eating and PPWR were investigated in four studies of good quality (two) and fair quality (two). Two of these studies (one of good and one of fair quality) indicated that higher restrained eating is associated with higher PPWL, which is an opposite trend compared to the findings of four studies in pregnancy, in which higher restrained eating tended to be associated with more weight gain. Since restrained eating is a more cognitive eating behavior (in some studies even called cognitive restraint)

compared to the other eating behaviors that are more related to emotions and other circumstances, these findings might possibly indicate that the postpartum is a more suitable timeframe for encouraging cognitive attempts to change eating behavior compared to pregnancy. The two other studies on restrained eating and PPWR (one of good and one of fair quality) did however not endorse these associations.

Higher external eating was found to be weakly associated with increased GWG by both of the identified studies that both had a small sample size (N = 113 and N = 161) and that were of fair and poor quality, respectively. A study among nonpregnant individuals showed similar findings (r = 0.14, p < .001),[64] although in another study, external eating was not significantly associated with weight (r = 0.05, p > .01),[59] so evidence among general populations is contradictory. One of the studies on external eating and GWG noted that there is high correlation between eating behaviors and therefore also tested the association between GWG and external, restrained, and emotional eating together. There was no longer statistically significant evidence for an association.[47] In all eating behavior questionnaires, the different types of eating behaviors are shown to be correlated to some extent.[11,36,53,55,65] However, of the studies identified in the current review, only the study by Van der Wijden et al.[47] took that correlation into account in their analyses.

More emotional eating in this review was found to be associated with increased GWG by three out of four studies of different quality (good, fair, and poor), although one of the studies pointed out that the association was mediated by frequency of food cravings. This might also have been the case for the other studies in this review; however, they did not investigate such mediation. In a qualitative study among Latina pregnant women, emotional eating emerged as a perceived difficulty for controlling GWG especially among women with obesity.[66] Contrastingly, a study in the current review only found a significant association between more emotional eating and higher GWG among women with a normal prepregnancy BMI.[38] The other studies on emotional eating did not stratify for BMI and could therefore not confirm these findings. The potential association between emotional eating and increased GWG as found in this review is in line with studies among nonpregnant populations, which showed that more emotional eating was associated with more weight gain and less weight loss.[23] The study that did not find an association between emotional eating and GWG was of fair quality; however, no validated questionnaire was used to inquire emotional eating. Instead, participants were asked for several types of emotions separately (anxiety, tiredness, boredom, stress, anger, depression, and loneliness) whether they believed this had contributed to GWG. Then, associations with

actual GWG were investigated. Thus, potentially the method of examining emotional eating might have hindered finding associations rather than associations being non-existing.

Food cravings during pregnancy are a well-known phenomenon and are perceived as a major challenge for controlling GWG by many women.[66] Among general populations, it is shown that food cravings are associated with higher BMI.[31,67] Three studies on food cravings in this review (one of fair and two of poor quality) reconfirmed that experiencing more food cravings potentially plays a role in increased GWG. Only one study on food cravings in the postpartum was identified. This study of fair quality did not find an association with PPWR. This might imply that food cravings especially play a role during pregnancy and not during postpartum, although this remains uncertain due to the limited number of available studies. Future longitudinal studies on food cravings starting in pregnancy and continuing in the postpartum could shed light on this presumption.

Intuitive eating was studied by four recent studies of good quality (one) and fair quality (three), and several associations were found between intuitive eating (sub)scales and both GWG as well as PPWR. All three studies in pregnancy indicated that higher intuitive eating scores were associated with lower GWG, and the study in postpartum indicated that higher intuitive eating scores were associated with less PPWR. This might potentially signify that intuitive eating is protective of increased GWG and PPWR, although causal pathways could not be established. Studies among nonpregnant populations similarly show that intuitive eating is associated with lower weight and BMI.[68] To a certain extent, intuitive eating overlaps with mindful eating, since both eating behaviors rely on awareness of hunger and satiety cues.[69] However, in the current review, only one study on mindful eating was identified, and this study of fair quality did not find evidence for an association with PPWR.

A limitation to this review is the scarcity of studies investigating the associations between eating behaviors and GWG and PPWR. Twenty studies were identified in this review, but not all studies covered all different types of eating behaviors. The majority of eating behaviors were only investigated in few studies. For example, there were only two studies to investigate external eating and GWG. Furthermore, there is no consensus on which questionnaire is the most appropriate to measure eating behavior. As a result, different questionnaires were used to assess the same eating behavior, compromising comparability of studies. For example, restrained eating was an outcome of the RRS, TFEQ, TFEQ-R18, DEBQ, and Eating Stimulus Index, yet these

questionnaires all use different questions and wordings to determine restrained eating. Adams et al. recently conducted a study to compare the Restraint Scale (RS) and the restrained eating scale of the DEBQ and came to the conclusion that the two questionnaires measure to a large extent the same subject. Yet, an important difference between the two scales is that the RS has stronger associations with external and disinhibited eating, food cravings, and BMI than the DEBQ. It is suggested that the RS is associated with unsuccessful restraint, whereas the restrained eating scale of the DEBQ measures successful restraint.[70] Additionally, eating behaviors are analyzed differently across studies. Whereas some studies formed two groups based on median scores (e.g., restrained vs. nonrestrained eating), others approached eating behaviors as continuous variables. Also, the weight variables were approached differently: variations for GWG included total GWG, weekly GWG, and number of women with adequate and excessive GWG based on IOM guidelines; variations for PPWR included weight retention at a certain time point in the postpartum period, and the number of women reaching prepregnancy weight. As a result of to the abovementioned heterogeneity of studies on different aspects, no meta-analysis could be performed. Besides, 16 out of 20 studies partly or entirely relied on self-reported weights, which might have introduced response bias. Only published scientific research is included in this review, and no gray literature search is conducted, which might have enhanced publication bias.

Conclusion

The available evidence for relationships between eating behaviors and peripartum weight change is too scarce, ambiguous, and of varying quality to draw robust conclusions. However, the findings of this review indicate that intuitive eating might potentially be related to a decreased GWG as well as a decreased PPWR. Restrained eating might potentially be related to an increased GWG and a greater PPWL, which would imply that the postpartum might be a more suitable phase for the initiation of cognitive behavioral lifestyle interventions than pregnancy. External, emotional, and disinhibited eating, as well as eating in response to cravings might potentially be related to an increased GWG. No evidence was found for associations between GWG and uncontrolled and mindful eating, and for PPWR and food cravings, external, emotional, disinhibited, uncontrolled, and mindful eating.

Overall, insufficient studies investigated relationships between eating behaviors and peripartum weight change, and part of the findings are contradictory. There is especially a lack of research on eating behavior in relation to weight in the postpartum period. Yet, it is vital to gain more insight

in this topic, as influencing eating behavior in this phase might lead to less PPWR, and as a result, lead to less long-term obesity and less complications in subsequent pregnancies. It is therefore highly recommended that future studies are undertaken to shed light on this. Prospective cohort studies commencing prior to pregnancy and continuing in pregnancy and postpartum are needed to gain insight in how eating behaviors evolve throughout the peripartum period and to better understand how they influence GWG and PPWR. The analyses should account for maternal prepregnancy BMI. The underlying mechanisms driving eating behavior, food intake, and peripartum weight change should also be taken into account. Subsequently, intervention studies targeting changes in eating behaviors should be developed and evaluated to determine whether this could contribute to preventing excessive GWG and PPWR.

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Supplementary files

Supplementary Table 2.1. Search terms in Pubmed format

Pregnancy/postpartum	"Pregnancy"[Mesh:NoExp] OR pregnancy[tiab] OR pregnancies[tiab] OR pregnant[tiab] OR gestation*[tiab] OR "child bearing"[tiab] OR childbearing[tiab] OR "Pregnant Women"[Mesh] OR prenatal[tiab] OR "pre natal"[tiab] OR antenatal[tiab] OR "ante natal"[tiab] OR perinatal[tiab] OR "peri natal"[tiab] OR "Postpartum Period"[Mesh:NoExp] OR postpartum[tiab] OR "post partum"[tiab] OR postnatal*[tiab] OR "post natal"[tiab]
Eating behavior	"eating behavior"[tiab] OR "eating behaviors"[tiab] OR "eating behaviour"[tiab] OR "eating behaviours"[tiab] OR "eating style"[tiab] OR "eating styles"[tiab] OR TFEQ[tiab] OR "three-factor eating questionnaire"[tiab] OR DEBQ[tiab] OR "dutch eating behavior questionnaire"[tiab] OR EEQ[tiab] OR "emotional eater questionnaire"[tiab] OR ESES[tiab] OR "eating self-efficacy scale"[tiab] OR "intuitive eating"[tiab] OR "food craving"[tiab] OR "food cravings"[tiab] OR "mindful eating"[tiab] OR "restricted eating"[tiab] OR "restrained eating"[tiab] OR "restraint eating"[tiab] OR "cognitive restraint"[tiab] OR "dietary restraint"[tiab] OR "emotional eating"[tiab] OR "external eating"[tiab] OR "uncontrolled eating"[tiab] OR disinhibition[tiab] OR "disinhibited eating"[tiab]
Weight	"Body Weight"[Mesh] OR weight[tiab]

Supplementary Table 2.2. NIH quality assessment tools' items

NIH quality assessment of observational cohort and cross-sectional studies
1. Was the research question or objective in this paper clearly stated?
2. Was the study population clearly specified and defined?
3. Was the participation rate of eligible persons at least 50%?
4. Were all the subjects selected or recruited from the same or similar populations (including the same time period)? Were inclusion and exclusion criteria for being in the study prespecified and applied uniformly to all participants?
5. Was a sample size justification, power description, or variance and effect estimates provided?
6. For the analyses in this paper, were the exposure(s) of interest measured prior to the outcome(s) being measured?
7. Was the timeframe sufficient so that one could reasonably expect to see an association between exposure and outcome if it exsted?
8. For exposures that can vary in amount or level, did the study examine different levels of the exposure as related to the outcome (e.g., categories of exposure, or exposure measured as continuous variable)?
9. Were the exposure measures (independent variables) clearly defined, valid, reliable, and implemented consistently across all study participants?
10. Was the exposure(s) assessed more than once over time?
11. Were the outcome measures (dependent variables) clearly defined, valid, reliable, and implemented consistently across all study participants?
12. Were the outcome assessors blinded to the exposure status of participants?
13. Was loss to follow-up after baseline 20% or less?
14. Were key potential confounding variables measured and adjusted statistically for their impact on the relationship between exposure(s) and outcome(s)?

NIH quality assessment of controlled intervention studies
1. Was the study described as randomized, a randomized trial, a randomized clinical trial, or an RCT?
2. Was the method of randomization adequate (i.e., use of randomly generated assignment)?
3. Was the treatment allocation concealed (so that assignments could not be predicted)?
4. Were study participants and providers blinded to treatment group assignment?
5. Were the people assessing the outcomes blinded to the participants' group assignments?
6. Were the groups similar at baseline on important characteristics that could affect outcomes (e.g., demographics, risk factors, co-morbid conditions)?
7. Was the overall drop-out rate from the study at endpoint 20% or lower of the number allocated to treatment?
8. Was the differential drop-out rate (between treatment groups) at endpoint 15 percentage points or lower?
9. Was there high adherence to the intervention protocols for each treatment group?

10. Were other interventions avoided or similar in the groups (e.g., similar background treatments)?
11. Were outcomes assessed using valid and reliable measures, implemented consistently across all study participants?
12. Did the authors report that the sample size was sufficiently large to be able to detect a difference in the main outcome between groups with at least 80% power?
13. Were outcomes reported or subgroups analyzed prespecified (i.e., identified before analyses were conducted)?
14. Were all randomized participants analyzed in the group to which they were originally assigned, i.e., did they use an intention-to-treat analysis?

NIH quality assessment of before-after studies with no control group
1. Was the study question or objective clearly stated?
2. Were eligibility/selection criteria for the study population prespecified and clearly described?
3. Were the participants in the study representative of those who would be eligible for the test/service/intervention in the general or clinical population of interest?
4. Were all eligible participants that met the prespecified entry criteria enrolled?
5. Was the sample size sufficiently large to provide confidence in the findings?
6. Was the test/service/intervention clearly described and delivered consistently across the study population?
7. Were the outcome measures prespecified, clearly defined, valid, reliable, and assessed consistently across all study participants?
8. Were the people assessing the outcomes blinded to the participants' exposures/interventions?
9. Was the loss to follow-up after baseline 20% or less? Were those lost to follow-up accounted for in the analysis?
10. Did the statistical methods examine changes in outcome measures from before to after the intervention? Were statistical tests done that provided p values for the pre-to-post changes?
11. Were outcome measures of interest taken multiple times before the intervention and multiple times after the intervention (i.e., did they use an interrupted time-series design)?
12. If the intervention was conducted at a group level (e.g., a whole hospital, a community, etc.) did the statistical analysis take into account the use of individual-level data to determine effects at the group level?

Supplementary Table 2.3. Baseline BMI, data collection time points and method of weight recording of studies on eating behavior and gestational weight gain

Author (year)	Participants	Baseline BMI	Measurement time point of baseline BMI	Data collection time points	Method of weight recording
Plante et al. (2020)	Pregnant women	Mean 25.1, SD 4.8 2% underweight 57% normal weight 25% overweight 17% obesity	Pre-pregnancy	Survey: 1st, 2nd, and 3rd trimester Weight: at delivery or at last prenatal visit (≥37th week GA)	Pre-pregnancy weight: self-reported Pregnancy weight: measured
Ledoux et al. (2020)	Pregnant women	Mean 25, SD 5.9	Pre-pregnancy	Survey: not reported Weight: ≥36 weeks GA	Pre-pregnancy weight: self-reported Pregnancy weight: retrieved from medical record
Tang et al. (2020)	Women in their 2nd pregnancy	43% normal weight 37% overweight 19% obesity	4-10 weeks GA	Survey: 4-10 weeks GA Weight: pre-pregnancy (if applicable), 4-10 weeks, 12 weeks, 18 weeks, 24 weeks, 30 weeks, 36 weeks GA	Measured
Garduño-Alanis et al. (2019)	Primigravid women with type 2 diabetes or gestational diabetes	23% normal weight 37% overweight 40% obesity	Pre-pregnancy	Survey: 48h after delivery Weight: end of 3rd trimester	Retrieved from medical record or if unavailable, self-reported
Paterson et al. (2019)	Pregnant women	Mean 25.5, SD 4.8	11-14 weeks GA	Survey and weight: 11-14 weeks GA, 18-22 weeks GA, 25-30 weeks GA, >35 weeks GA.	Measured
Plante et al. (2019)	Pregnant women	Mean 25.7, SD 5.8	Pre-pregnancy	Survey and weight: 1st, 2nd and 3rd trimester	Pre-pregnancy weight: self-reported Pregnancy weight: retrieved from medical record
Blau et al. (2018)	Pregnant women	46% BMI <25 22.5% BMI 25-29.9 31.4% BMI >30	Pre-pregnancy	Survey and weight: mean 24.05 (SD 8.84) weeks GA	Self-reported

Heery et al. (2016)	Pregnant women	Mean 23.9, range 15-49.9	At booking appointment (pregnancy)	Survey: mean 15.4 (SD 3.9) weeks GA Weight: last measured weight in pregnancy	Pre-pregnancy weight: self-reported Pregnancy weight: retrieved from medical record
Hill et al. (2016)	Pregnant women, GA ~29 weeks	Cravings: mean 25.8, SD 4.9 No Cravings: mean 25.5, SD 4.9	<16 weeks of gestation (mean gestational age 12.1 weeks)	Survey: unclear Weight: 28 weeks GA.	Pre-pregnancy weight: retrieved from medical record Pregnancy weight: measured
Slane & Levine (2015)	Pregnant women who quit smoking as a result of pregnancy, GA ≥28 weeks	Mean 26.3, SD 7.0	Pre-pregnancy	Survey and weight: mean 34 weeks GA	Pre-pregnancy weight: self-reported Pregnancy weight: measured
Van der Wijden et al. (2014)	Pregnant women, GA 15 and 35 weeks	9% underweight 64% normal weight 27% overweight/ obesity	Pre-pregnancy	Survey and weight: 15 and 35 weeks GA	Pre-pregnancy weight: self-reported Pregnancy weight: measured
Allison et al. (2012)	Pregnant African American women; GA 14-24 weeks; pregravid BMI ≥ 25	Mean 32.4, SD 7.8	Pre-pregnancy	Survey: 14-24 weeks GA Weight: last measured weight in pregnancy	Pre-pregnancy weight: self-reported Pregnancy weight: retrieved from medical record
Mumford et al. (2008)	Pregnant women, mean GA 14 weeks	14% underweight 51% normal weight 11% overweight 24% obesity	Pre-pregnancy	Unclear	Pre-pregnancy weight: self-reported Pregnancy weight: measured
Clark & Ogden (1999)	Primigravid women, GA 24-28 weeks	Mean 26.6, SD 3.1	24-28 weeks of gestation	Survey: between 24-28 weeks GA Weight: unclear	Self-reported
Conway et al. (1999)	Pregnant Caucasian women, from GA ~12 weeks	Restrained eating: mean 22, SD 2.4 Unrestrained eating: mean 20.7, SD 1.96	Pre-pregnancy	Survey: 12 and 30 weeks GA Weight: last known pregnancy weight	Self-reported

Abbreviations: BMI = body mass index; GA = gestational age; PP = postpartum PPWL = postpartum weight loss; PPWR = postpartum weight retention

Supplementary Table 2.4. Baseline BMI, data collection time points and method of weight recording of studies on eating behavior and postpartum weight

Author (year)	Participants	Baseline BMI	Measurement time point of baseline BMI	Data collection time points	Method of weight recording
Most et al. (2020)	Women with BMI ≥30	Among PPWL: mean 35.7, SD 1.2; among PPWR: mean 36.4, SD 0.9	13-16 weeks GA	Survey and weight: 13-16 weeks GA, 48-56 weeks PP	Measured
Phelan et al. (2019)	Women 6 and 12 months postpartum with pre-pregnancy BMI >25	Mean 32.5, SD 5.3	Pregnancy, mean gestational age 13.6 weeks	Survey and weight: 35-36 weeks GA and 48-56 weeks postpartum	Pre-pregnancy weight: self-reported Postpartum weight: measured
Quansah et al. (2019)	Women with GDM	Mean 29.9, SD 4.9	Pre-pregnancy	Survey: first GDM visit and 1 year postpartum Weight: first GDM visit	Pre-pregnancy weight: retrieved from medical record or self-reported. Pregnancy and postpartum weight: measured
Phelan et al. (2014)	Women 6 and 12 months postpartum	Standard care: mean 26.5, SD 5.9 Intervention: mean 26.3, SD 5.6	10-16 weeks of gestation	Survey and weight: 30 weeks GA, 6 months postpartum, and 12 months postpartum	Pre-pregnancy weight: self-reported Pregnancy and postpartum weight: measured
Cahill et al. (2012)	Low-income women with BMI ≥ 25; 0-4 months postpartum	Mean 32, SD 0.8	0-4 months postpartum	Survey and weight: week 1 and 10 of the program within 0-4 months postpartum	Pre-pregnancy and pregnancy weight: self-reported Postpartum weight: measured

Abbreviations: BMI = body mass index; GA = gestational age; PP = postpartum PPWL = postpartum weight loss; PPWR = postpartum weight retention



CHAPTER 3.

Evolution of postpartum weight and body composition after excessive gestational weight gain: the role of lifestyle behaviors

Data from the INTER-ACT control group

Bijlholt, M., Ameye, L., van Uytsel, H., Devlieger, R., & Bogaerts, A. (2021). International Journal of Environmental Research and Public Health, 18(12), 6344.

Abstract

Women with excessive gestational weight gain are at increased risk of postpartum weight retention and potentially also unfavorable body composition. Insight into the lifestyle behaviors that play a role in the evolution of postpartum weight and body composition among these women could aid identification of those at highest risk of long-term adverse outcomes. This secondary analysis of the INTER-ACT randomized controlled trial investigates control group data only (n = 524). The evolution of weight retention, percentage loss of gestational weight gain, fat percentage, waist circumference, and associated lifestyle behaviors between 6 weeks and 12 months postpartum were assessed using mixed model analyses. At 6 weeks postpartum, every sedentary hour was associated with 0.1% higher fat percentage (P = 0.01), and a higher emotional eating score was associated with 0.2% higher fat percentage (P < 0.001) and 0.3 cm higher waist circumference (P < 0.001). Increase in emotional eating score between 6 weeks and 6 months postpartum was associated with a 0.4 kg (P = 0.003) increase in postpartum weight retention from 6 months onwards. Among women with overweight, an increase in the uncontrolled eating score between 6 weeks and 6 months postpartum was associated with a 0.3 kg higher postpartum weight retention (P = 0.04), and 0.3% higher fat percentage (P = 0.006) from 6 months onwards. In conclusion, sedentary and eating behaviors play important roles in postpartum weight and body composition of women with excessive gestational weight gain and should therefore be incorporated as focal points in lifestyle interventions for this population.

Introduction

The retention of pregnancy weight after delivery contributes to long-term overweight and associated morbidities such as cardiovascular diseases, type 2 diabetes mellitus and certain cancer types [1–4]. Postpartum weight normalization is therefore highly recommended. However, 75% of women do not return to their pre-pregnancy weight in the year following delivery [1]. Studies show a mean postpartum weight retention (PPWR) of four to five kilograms one year after delivery [1,5]. An important risk factor for PPWR is excessive gestational weight gain (GWG) [5,6], which occurs in approximately 35% to 50% of pregnancies [7,8]. Women with an excessive GWG were previously found to have a three kilogram higher PPWR three years after delivery compared to women who had an adequate GWG [9]. It is therefore of great public health importance that women with previous excessive GWG receive special attention for the reduction of PPWR.

Aside from GWG, maternal age, race, employment status, breastfeeding, physical activity and food intake are suggested to affect PPWR [10–14]. Certain eating behaviors might also play a role, as a recent systematic review shows that more restrained and intuitive eating are potentially related to decreased postpartum weight retention [15]. Other eating behaviors such as emotional eating and uncontrolled eating have not yet been studied in relation to PPWR, though they are associated with weight in the general population [16,17]. It should be investigated whether these determinants play a role in PPWR and specifically among women with excessive GWG.

Weight and body mass index (BMI) are commonly reported measures in postpartum studies, yet these measures alone do not provide a complete picture of body composition. To illustrate, BMI is correlated with fat mass, but fat percentage can strongly differ between individuals with the same BMI [18,19]. An increased fat percentage is associated with metabolic syndrome and cardiovascular risk [20,21]. BMI cannot establish central adiposity, which is likewise related to metabolic syndrome and cardiovascular diseases [22,23]. Waist circumference is a useful and accurate measure of central adiposity [18,24]. Taking into account fat percentage and waist circumference in addition to weight and BMI is therefore of added value.

Although body composition is related to lifestyle factors such as food intake and physical activity among general populations [25,26], little research is available that investigates relationships between lifestyle and body composition in the postpartum period. In addition, more knowledge on the evolution and factors associated with PPWR specifically among women

with excessive GWG could aid in the development of interventions targeting this high-risk group, as targeted interventions are currently unavailable [27]. Therefore, the aim of this paper is to investigate whether lifestyle factors including food intake, eating behavior, physical activity and sedentary behavior as well as breastfeeding are associated with PPWR, percentage GWG loss (% GWGL), fat percentage and waist circumference changes in the first year after delivery among women with excessive GWG.

Materials and methods

The present study is a secondary analysis of the INTER-ACT randomized controlled trial (RCT). For the purpose of the current analyses, data from control group participants of the INTER-ACT RCT were used. The methodology of the INTER-ACT study is described in detail elsewhere [28]. In brief, the INTER-ACT RCT provided a blended care lifestyle intervention to women with preceding excessive GWG, with the aim to reduce pregnancy- and birth-related complications in a next pregnancy. The intervention and data collection comprised two phases: a postpartum phase and a subsequent pregnancy phase. Postpartum data collection took place at six weeks, six months and twelve months after delivery. Subsequently, data was collected every six months until a next pregnancy. Pregnancy data collection took place once in every trimester of the pregnancy. For the purpose of the current analyses, only the postpartum data collection at six weeks, six months and twelve months after delivery for the control group participants was included. Outcomes of interest in the current analyses were postpartum weight retention, percentage of GWG lost, fat percentage and waist circumference. More details on these outcomes are described in the section on anthropometry.

Recruitment

From May 2017 until April 2019, participants were recruited 2 to 3 days after delivery by research midwives in six hospitals in three different regions in Flanders, Belgium: University Hospital Leuven, University Hospital Antwerp, Gasthuiszusters Hospital Antwerp, St-Franciscus Hospital in Heusden-Zolder, Jessa Hospital in Hasselt and Hospital Oost-Limburg in Genk.

Eligibility criteria

Women were eligible for participation in the study if they had excessive GWG in the preceding pregnancy according to the National Academy of Medicine guidelines, being a GWG > 16 kg for women with normal weight,

>11.5 kg for women with overweight and >9 kg for women with obesity [29]. Further eligibility criteria were age 18 years and being sufficiently proficient in Dutch to independently fill out questionnaires. Women were ineligible for participation after stillbirth, if they delivered twins, if they had a history of bariatric surgery or a planned one, or if they had a chronic disorder such as diabetes mellitus, renal disease or a psychiatric disorder.

Participants

Details on the sample size calculation of the INTER-ACT study are described in the study protocol [28]. In the larger RCT, 1450 participants were recruited, of which 724 were randomized into the intervention group and 726 into the control group. Randomization was performed by the electronic Case Report Form (eCRF) system. Blinding could not be applied due to the nature of the RCT. For the current analyses, only the control group participants were selected. They received usual care only. Two participants were removed because they did not meet eligibility criteria. Seven participants had an underweight pre-pregnancy BMI and were excluded from the analyses. This resulted in 717 participants who were eligible for the current analyses. The first study visit (six weeks postpartum) was completed by 524 control group participants; 386 completed the second study visit (six months postpartum); 311 completed the third study visit (12 months postpartum) (Figure 3.1).

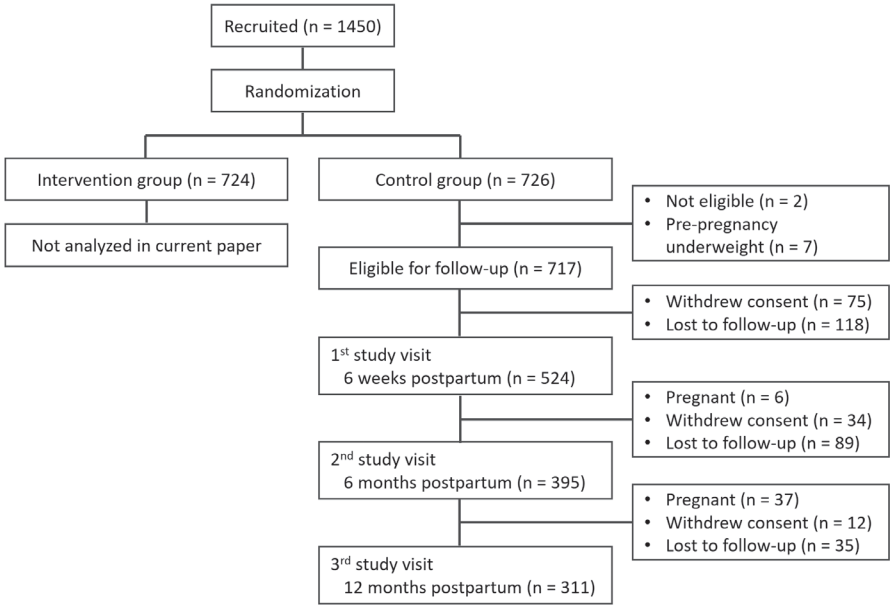

Figure 3.1. Flow chart of participant follow-up.

Data collection

An eCRF was used to capture all data. Data from the medical records were collected at recruitment. Anthropometric and questionnaire data were collected at 6 weeks (median 7.1, IQR 6.3–8.1), 6 months (median 6.1, IQR 5.9–6.4) and 12 months postpartum (median 12.1, IQR 11.9–12.3). A timeframe of two weeks before to four weeks after 6 weeks, 6 months and 12 months postpartum was allowed for the measurements for feasibility. Trained researchers and research assistants collected data at the home of the participant, at the hospital or at a different location in accordance with the preference of the participants. If participants became pregnant again within the first 12 months postpartum, data collected during that pregnancy were excluded from the current analyses.

Medical record data

Data on method of conception, parity, sex of the infant and (pre-)pregnancy weight were retrieved from the medical records. Pre-pregnancy weight and weight at delivery were self-reported or measured by a caregiver and were used to calculate GWG and determine excessive GWG according to the National Academy of Medicine guidelines [29].

Anthropometry

Weight and fat mass were determined using a Tanita MC 780 SMA bio-electric impedance device (Tanita Corporation, Tokyo, Japan) with three frequencies (5, 50 and 250 kHz). The measurement was taken in light clothing and bare feet while standing on the scale and holding grips with integrated electrodes for the measurement of body composition. Height was measured with a Seca 213 stadiometer to the nearest 0.1 cm while standing straight with the head oriented in the Frankfurt plane position. Waist circumference was measured to the nearest 0.1 cm midway between the lowest rib and the hip bone using a Seca 201 measuring tape.

Postpartum weight retention is the difference between weight at a given point of time in the postpartum period and pre-pregnancy weight. Percentage gestational weight gain loss (% GWGL) was computed for every respective measurement time point (six weeks, six months and twelve months postpartum), as follows:

$$\%GWGL = \frac{\text{weight at delivery} - \text{postpartum weight}}{\text{gestational weight gain}} \times 100\%$$

Questionnaires

Personalized links to the online questionnaires were sent out from the eCRF system. All participants received questionnaires according to a fixed time scheme: two weeks in advance of the appointment; in the case of non-response, reminders were sent one week and two days in advance of the appointment.

Questions on sociodemographic factors such as level of education, employment status and ethnicity were only included in the first questionnaire. Breastfeeding questions were based on previous studies and included items on exclusive breastfeeding, combined or formula feeding and duration of breastfeeding [30]. Depressive feelings in the past were queried in one question based on earlier publications [31,32].

Information on food intake was obtained using a validated 24-item Food Frequency Questionnaire [33]. For every item, frequency and quantity of intake were queried. Total energy and macronutrients were calculated.

Eating behavior was assessed using the validated Three-Factor Eating Questionnaire Revised 18-item version (TFEQ-R18) [34]. Eighteen Likert-scale items queried restrained eating, emotional eating, and uncontrolled eating. Restrained eating refers to “a tendency to constantly and consciously restrict one’s food intake instead of using physiological cues, hunger and satiety, as regulators of food intake”; uncontrolled eating refers to “a tendency to overeat, with the feeling of being out of control”; emotional eating refers to “the tendency to eat in response to negative emotions”[35]. Total scores for every type of eating behavior were converted to a scale ranging from 0 to 100, representing the relative proportion of the highest possible raw scores [35].

The International Physical Activity Questionnaire (IPAQ) was used to assess physical activity and sedentary behavior. The IPAQ includes questions on physical activity related to one’s job, transportation, housework, house maintenance, caring for family, recreation, sport, leisure time and time spent sitting. Physical activity was expressed as the metabolic equivalent of task minutes (MET-minutes) per week, and sedentary time was expressed in minutes per week [36].

Ethical approval and informed consent

Ethical approval for this study was obtained on 9 March 2017 by the medical ethics committees of all six participating hospitals (protocol code B322201730956), and all participants provided informed consent at recruitment. The study was pre-registered on ClinicalTrials.gov (NCT02989142).

Data analysis

Data were analyzed using SPSS version 27 and SAS version 9.4. Descriptive characteristics were presented as mean and standard deviation or median and interquartile range for continuous variables and number and percentage for categorical variables.

For univariate analyses, the study population was divided into women who had a PPWR < 5 kg and ≥ 5 kg. This cut-off represents substantial PPWR with potential long-term consequences and has been regularly utilized in previous studies [13,14,37,38]. Differences in categorical variables were assessed with likelihood ratio chi-square test or Fisher Exact test and differences in continuous variables were assessed with unpaired t-test or Mann-Whitney U test. A P-value < 0.05 was considered statistically significant. The same tests were performed to compare dropouts to non-dropouts.

For each of the four outcome variables—PPWR, % GWGL, fat percentage and waist circumference evolution—a mixed model was constructed by considering time (in months), pre-pregnancy BMI class, level of education, employment status, method of conception, parity, sex of infant, depressive feelings in the past, amount of excessive GWG, breastfeeding, physical activity, sedentary time, caloric intake, macronutrient intake and eating behavior as possible explanatory variables. For each of the explanatory variables, the interaction term with BMI class was considered (e.g., different effect of breastfeeding on the outcome in obese/overweight compared to normal weight) as was the interaction term with time (stronger/lower effect in obese or overweight, over time). A broken line regression was considered for the time effect, with a break point at 6 months, allowing a difference in effect during the first months postpartum compared to after 6 months postpartum. The mixed models use a random intercept, random slope and unstructured working correlation matrix in order to take into account the dependency between the consecutive body composition measurements of the same mother over time.

Results

Participant characteristics

A total of 717 participants were eligible for the current analyses, of which 524 completed the first study visit at six weeks postpartum, 386 the second study visit at six months postpartum, and 311 the third study visit at 12 months postpartum (Figure 3.1).

Table 3.1 presents characteristics of the 524 participants who completed at least one study visit. Women who dropped out before the third study visit at 12 months postpartum significantly differed from those who completed the third study visit in terms of education (respectively, 25.1% and 36.2% held a master's degree, P = 0.003), pre-pregnancy BMI (respectively, 40.4% and 54.7% had a normal BMI, P = 0.006), GWG among the overweight subgroup (respectively, 17 and 15 kg, P = 0.007), breastfeeding (respectively, 49.8% and 59.8% exclusively breastfed at six weeks postpartum, P = 0.03), and history of depressive feelings (respectively, 21.1% and 12.3%, P = 0.009) (Supplementary Table 3.1).

At 12 months postpartum, 30% of the women had returned to their pre-pregnancy weight. Mean % GWGL at 12 months postpartum was 89.2% (SD 32.2). Almost one in four women (23.8%) retained 5 kg or more at 12 months postpartum. Women with ≥ 5 kg PPWR more often had education up to 18 years of age and less often a master's degree or higher compared to women with < 5 kg PPWR at 12 months postpartum. Furthermore, women with ≥ 5 kg PPWR at 12 months postpartum had a higher GWG in the preceding pregnancy compared to women with < 5 kg PPWR, except for women with an obese pre-pregnancy BMI. Women with ≥ 5 kg PPWR at 12 months postpartum had already a higher PPWR at 6 weeks postpartum than women who had < 5 kg PPWR one year postpartum. Women in the overweight BMI category who had ≥ 5 kg PPWR at a year postpartum had already a higher fat percentage at six weeks postpartum. Women with normal weight and ≥ 5 kg PPWR at 12 months had a higher waist circumference at six weeks postpartum (Table 3.2).

Table 3.1. Participant characteristics (n = 524)

		Sample at 6 weeks postpartum (baseline) (n = 524)
Age at birth, mean (SD)		31.4 (3.9)
Parity, n (%)	Primiparous	295 (56.3)
	Multiparous	229 (43.7)
Sex of infant, n (%)	Boy	274 (52.3)
	Girl	250 (47.7)
Method of conception, n (%)	Spontaneous	473 (92)
	ART	41 (8)
	Missing	10
Education, n (%)	Up to 18 years of age	149 (29.2)
	Bachelor	199 (39)
	Master or higher	162 (31.8)
	Missing	14
Employment status, n (%)	Employed	466 (91.4)
	Unemployed	44 (8.6)
	Missing	14
Ethnicity, n (%)	White European	462 (90.6)
	Other ethnicity	48 (9.4)
	Missing	14
Pre-pregnancy BMI, n (%)	NW	256 (48.9)
	OW	187 (35.7)
	OB	81 (15.5)
Gestational weight gain in kg, median (IQR)	Among NW	19 (17-21)
	Among OW	16 (13-19)
	Among OB	14 (12-17)
PPWR in kg at 6 weeks PP, mean (SD)	Among NW	7.8 (4)
	Among OW	6.2 (4.2)
	Among OB	5.2 (5.1)
Sedentary time per day in hours, median (IQR)		5.0 (3.7-7.0)
Emotional eating score, median (IQR)		33 (11-55)
Uncontrolled eating score, mean (SD)		42 (20)

		Sample at 6 weeks postpartum (baseline) (n = 524)
Exclusive breastfeeding at 6 weeks PP, n (%)	Yes	283 (55.8)
	No	224 (44.2)
	Missing	17
History of depressive feelings, n (%)	Yes	79 (15.8)
	No	421 (84.2)
	Missing	24

ART = assisted reproductive treatment; BMI = body mass index; NW = normal weight; OB = obesity; OW = overweight; PP = postpartum; PPWR = postpartum weight retention.

Table 3.2. Differences between participants with <5 kg and ≥5 kg postpartum weight retention at 12 months postpartum (n = 311).

		PPWR <5 kg at 1 year PP (n=237)	PPWR ≥5 kg at 1 year PP (n=74)	P-value*
Age at birth, mean (SD)		31.4 (3.6)	31.6 (4.3)	0.60
Parity, n (%)	Primiparous	140 (59.1)	40 (54.1)	0.45
	Multiparous	97 (40.9)	34 (45.9)	
Sex of infant, n (%)	Boy	118 (49.8)	36 (48.6)	0.86
	Girl	119 (50.2)	38 (51.4)	
Method of conception, n (%)	Spontaneous	217 (94.8)	64 (88.9)	0.08
	ART	12 (5.2)	8 (11.1)	
	Missing	8	2	
Education, n (%)	Up to 18y of age	46 (19.7) [a]	28 (38.4) [a]	0.001
	Bachelor	92 (39.3)	30 (41.1)	
	Master or higher	96 (41.0) [a]	15 (20.5) [a]	
	Missing	3	1	
Employment status, n (%)	Employed	218 (93.2)	65 (89)	0.25
	Unemployed	16 (6.8)	8 (11)	
	Missing	3	1	
Ethnicity, n (%)	White European	216 (92.3)	67 (91.8)	0.88
	Other ethnicity	18 (7.7)	6 (8.2)	
	Missing	3	1	
Pre-pregnancy BMI, n (%)	NW	136 (57.4)	34 (45.9)	0.17
	OW	73 (30.8)	26 (35.1)	
	OB	28 (11.8)	14 (18.9)	
Gestational weight gain in kg, median (IQR)	Among NW	18 (17-20.2)	20.5 (18.4-24.3)	0.002
	Among OW	15 (13-17)	16.3 (14-19)	0.04
	Among OB	13.2 (12-15.9)	14 (11-17.6)	0.45
Exclusive breastfeeding at 6 weeks PP, n (%)	Yes	144 (65.5)	37 (56.1)	0.17
	No	76 (34.5)	29 (43.9)	
	Missing	17	8	
Exclusive breastfeeding at 6 months PP, n (%)	Yes	68 (31.3)	17 (28.3)	0.66
	No	149 (68.7)	43 (71.7)	
	Missing	20	14	

		PPWR <5 kg at 1 year PP (n=237)	PPWR ≥5 kg at 1 year PP (n=74)	P-value*
PPWR in kg at 6 weeks PP, mean (SD)	Among NW	7 (3.9)	10.5 (4.2)	<0.001
	Among OW	5.2 (3.9)	8.1 (4.3)	0.002
	Among OB	3.2 (2.8)	6.2 (4.3)	0.009
%GWGL at 6 weeks PP, mean (SD)	Among NW	64.9 (14.7)	51.8 (13.7)	<0.001
	Among OW	68.1 (21.3)	54.2 (20.7)	0.005
	Among OB	77.6 (20.2)	59.6 (28.1)	0.022
Fat % at 6 weeks PP, mean (SD)	Among NW	31.6 (4)	32.8 (3.6)	0.12
	Among OW	36.3 (2.9)	38.1 (2.9)	0.02
	Among OB	40.1 (2.2)	41.6 (4.3)	0.15
Waist circumference in cm at 6 weeks PP, median (IQR)	Among NW	81.3 (78-85.3)	84.2 (81.1-87.9)	0.02
	Among OW	88.5 (84.7-92.4)	90.6 (87.9-94.1)	0.29
	Among OB	96.5 (91.1-102.9)	102.1 (95.4-105.1)	0.09
History of depressive feelings, n (%)	Yes	23 (10)	14 (19.7)	0.03
	No	207 (90)	57 (80.3)	
	Missing	7	3	

* P-value for differences between groups.

[a] Significant differences after Bonferroni correction.

ART = assisted reproductive treatment; BMI = body mass index; GWGL = gestational weight gain loss; NW = normal weight; OB = obesity; OW = overweight; PP = postpartum; PPWR = postpartum weight retention.

Factors associated with evolution of postpartum weight and body composition

Pre-pregnancy BMI, amount of excessive GWG, sex of the infant, initiation of exclusive breastfeeding, a history of depressive feelings, parity, sedentary behavior, emotional eating and uncontrolled eating behaviors were significantly associated with PPWR, % GWGL, fat percentage and/or waist circumference (Table 3.3). No statistically significant evidence was found that restrained eating behavior, energy intake, macronutrient intake and physical activity were associated with any of the outcomes. The Supplementary Tables 3.2 and 3.3 show the original models with estimates, standard errors and P-values. Supplementary File 3.1 provides sample cases that illustrate the meaning of the values in Table 3.3.

Table 3.3. Factors at 6 weeks postpartum in association with evolution of weight and body composition up to 12 months postpartum (n = 524 at 6 weeks, n = 395 at 6 months, n = 311 at 12 months postpartum)

		PPWR in kg			%GWGL			Fat %			Waist circumference in cm		
		Starting point (W6)	Monthly evolution W6-M6	Monthly evolution M6-M12	Starting point (W6)	Monthly evolution W6-M6	Monthly evolution M6-M12	Starting point (W6)	Monthly evolution W6-M6	Monthly evolution M6-M12	Starting point (W6)	Monthly evolution W6-M6	Monthly evolution M6-M12
BMI [a] (REF)	NW	5.5	-0.5	-0.3	66.9	3.2	2	30.5	-0.5	-0.3	81.9	-1.0	-0.5
	OW	3.9	-0.2	-0.2	66.9	2.2	2	36.2	-0.3	-0.3	87.7	-0.6	-0.4
	OB	2.1	0.1	-0.1	66.9	0.6	1.8	39.3	-0.1	-0.3	98.2	-0.5	-0.5
EGWG - per 1 kg	NW	+1.0	-0.04	-0.04	-2	NS	NS	+0.5	NS	NS	+0.4	NS	NS
	OW	+0.8	-0.04	-0.04	-2	NS	NS	+0.2	NS	NS	+0.4	NS	NS
	OB	+1.0	-0.04	-0.04	-2	NS	NS	+0.2	NS	NS	+0.4	NS	NS
Boy	NW	NS	-0.2	+0.1	NS	+0.9	NS	+1	NS	NS	NS	-0.2	+0.2
	OW	NS	-0.2	+0.1	NS	+0.9	NS	+1	NS	NS	NS	-0.2	+0.2
	OB	NS	-0.2	+0.1	NS	+0.9	NS	+1	NS	NS	NS	-0.2	+0.2
Started exclusive BF	NW	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
	OW	-1.1	NS	NS	+7.9	NS	NS	-1.3	NS	NS	NS	NS	NS
	OB	-2.2	NS	NS	+14.5	NS	NS	NS	NS	NS	NS	NS	NS
History of depression	NW	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
	OW	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
	OB	-2.3	NS	NS	+17.5	NS	NS	NS	NS	NS	NS	NS	NS
Multiparity	NW	NS	NS	NS	-8	NS	NS	NS	NS	NS	NS	NS	NS
	OW	NS	NS	NS	-8	NS	NS	NS	NS	NS	NS	NS	NS
	OB	NS	NS	NS	-8	NS	NS	NS	NS	NS	NS	NS	NS

		PPWR in kg			%GWGL			Fat %			Waist circumference in cm		
		Starting point (W6)	Monthly evolution W6-M6	Monthly evolution M6-M12	Starting point (W6)	Monthly evolution W6-M6	Monthly evolution M6-M12	Starting point (W6)	Monthly evolution W6-M6	Monthly evolution M6-M12	Starting point (W6)	Monthly evolution W6-M6	Monthly evolution M6-M12
Sedentary time - per 1 hour daily	NW	NS	NS	NS	NS	NS	NS	+0.1	NS	NS	NS	NS	NS
	OW	NS	NS	NS	NS	NS	NS	+0.1	NS	NS	NS	NS	NS
	OB	NS	NS	NS	NS	NS	NS	+0.1	NS	NS	NS	NS	NS
Emotional eating score - per 10 points	NW	NS	NS	NS	NS	NS	NS	+0.2	NS	NS	+0.3	NS	NS
	OW	NS	NS	NS	NS	NS	NS	+0.2	NS	NS	+0.3	NS	NS
	OB	NS	NS	NS	NS	NS	NS	+0.2	NS	NS	+0.3	NS	NS
Uncon-trolled eating score – per 10 points	NW	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
	OW	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
	OB	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

BF = breastfeeding; BMI = body mass index; EGWG = excessive kilograms gestational weight gain; M6 = 6 months postpartum; M12 = 12 months postpartum; NW = normal weight; NS = not significant; OB = obesity; OW = overweight; PPWR = postpartum weight retention; W6 = 6 weeks postpartum; %GWGL = percentage gestational weight gain loss

[a] Pre-pregnancy BM

Full model in Supplementary Table 3.2

Example of interpretation in Supplementary File 3.1

Pre-pregnancy BMI

Women with overweight and obesity started off from six weeks postpartum with less PPWR (3.9 and 2.1 kg, respectively) but a higher fat percentage (36.2 and 39.3%, respectively) and higher waist circumference (87.7 and 98.2 cm, respectively) than women with normal weight (PPWR 5.5 kg; fat 30.5%; waist 81.9 cm). BMI category did not play a role in the starting point of % GWGL (66.9% in all BMI categories) (Table 3.3).

Between six weeks and six months postpartum, a slower monthly decrease of PPWR, fat percentage and waist circumference and a slower monthly increase in % GWGL was observed among women with overweight and obesity compared to women with normal weight. For women with obesity, there was a small monthly increase instead of a decrease in PPWR from six weeks to six months postpartum (Table 3.3).

Between 6 months and 12 months postpartum, the monthly evolution of all outcomes slowed down for women with normal weight. A slower evolution after six months postpartum was also seen among women with overweight for the outcomes % GWGL and waist circumference. The evolution of PPWR and fat percentage remained stable over time for women with overweight. In contrast, women with obesity showed a slightly steeper monthly decrease of PPWR and fat percentage and a slightly larger monthly increase in % GWGL from 6 months to 12 months postpartum compared to the monthly evolutions that were observed between six weeks and six months postpartum. Still, the outcomes evolved at a slower or similar pace among women with overweight and obesity compared to women with normal weight (Table 3.3). Figure 3.2 provides insight into the estimated starting point and evolution of PPWR for the three BMI groups.

Excessive GWG

For every kilogram of GWG exceeding the guidelines, women with normal weight and obesity had one kilogram PPWR extra starting from six weeks postpartum; women with overweight had 0.8 kg of PPWR extra. The more kilograms a woman of any BMI category gained in excess of the guideline, the steeper the monthly decrease of PPWR over time (i.e., a decrease of 0.04 kg per kg excessive GWG per month) (Table 3.3).

Furthermore, women in all BMI groups had a 2% lower % GWGL for every kilogram exceeding the guideline and a 0.4 cm higher waist circumference starting from six weeks postpartum onwards. For fat percentage, women with normal weight had a 0.5% higher starting point for every kilogram of

excessive GWG, and women with overweight and obesity, 0.2% higher. The monthly evolutions of % GWGL, fat percentage and waist circumference were not associated with the amount of kilograms exceeding the GWG guidelines for any BMI category (Table 3.3).

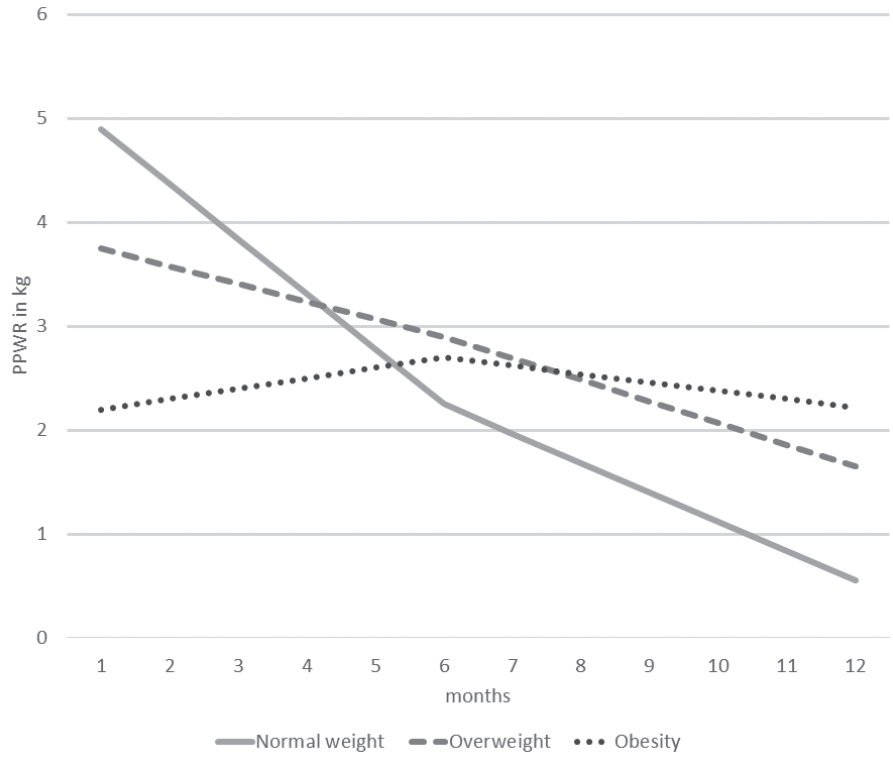

Figure 3.2. The estimated evolution of postpartum weight retention among women with normal weight, overweight and obesity based on the multivariate mixed model (N = 524 at 6 weeks, N = 395 at 6 months, N = 311 at 12 months postpartum).

Lifestyle

Sedentary time was a significantly associated with fat percentage starting from six weeks postpartum: every hour per day spent sitting contributed to a 0.1% higher fat percentage from six weeks postpartum onwards. A higher score in emotional eating was associated with a higher fat percentage (+0.2%) and larger waist circumference (+0.3 cm) from six weeks postpartum onwards (Table 3.3).

When examining determinants at six months postpartum in addition to the baseline determinants, an increasing emotional eating score between six weeks and six months postpartum was found to be associated with less favorable PPWR (+0.4 kg) and % GWGL (0.02) from six months postpartum onwards. Likewise, an increasing score for uncontrolled eating was associated with a higher PPWR (+0.3 kg), lower % GWGL (0.02%), and higher fat percentage (+0.3%) from six months postpartum onwards, but only for women with overweight (Table 3.4).

Women with overweight and obesity who started exclusive breastfeeding had a lower postpartum weight retention (1.1 and 2.2 kg, respectively) and a higher % GWGL (+7.9% and +14.5%, respectively) starting from six weeks postpartum onwards than those who did not start exclusive breastfeeding. In addition, women with overweight who started exclusive breastfeeding had a 1.3% lower fat percentage from six weeks postpartum onwards (Table 3.3).

Women with obesity who had experienced depressive feelings in the past showed a 2.3 kg lower PPWR and a 17.5% higher % GWGL starting from six weeks postpartum onwards compared to women with obesity who had not experienced depressive feelings.

Physical activity, dietary intake and restrained eating behavior were not associated with PPWR, % GWGL, fat percentage or waist circumference in the models.

Table 3.4. Factors at 6 months postpartum in association with evolution of weight and body composition up to 12 months postpartum

		PPWR in kg		%GWGL		Fat %		Waist circumference in cm	
		Starting point (M6)	**Monthly evolution M6-M12**	**Starting point (M6)**	**Monthly evolution M6-M12**	**Starting point (M6)**	**Monthly evolution M6-M12**	**Starting point (M6)**	**Monthly evolution M6-M12**
Δ emotional eating score [a] - per 10 points	NW	+0.4	NS	-0.02	NS	NS	NS	NS	NS
	OW	+0.4	NS	-0.02	NS	NS	NS	NS	NS
	OB	+0.4	NS	-0.02	NS	NS	NS	NS	NS
Δ uncontrolled eating score [a] - per 10 points	NW	NS	NS	NS	NS	NS	NS	NS	NS
	OW	+0.3	NS	-0.02	NS	+0.3	NS	NS	NS
	OB	NS	NS	NS	NS	NS	NS	NS	NS

M6 = 6 months postpartum; M12 = 12 months postpartum; NW = normal weight; OB = obesity; OW = overweight; PPWR = postpartum weight retention; %GWGL = percentage gestational weight gain loss

[a] Difference in score between M6 and W6 postpartum.

Full model in Supplementary Table 3.3.

Demographic factors

Women who gave birth to a boy showed a slightly steeper monthly decrease of PPWR and waist circumference from six weeks to six months postpartum, but an opposite trend was seen from 6 months to 12 months postpartum (Table 3.3). At 12 months postpartum, women who gave birth to a boy were estimated to have a 0.3 kg higher PPWR compared to those who gave birth to a girl. Women who gave birth to a boy had a slightly larger monthly increase in % GWGL between six weeks and six months postpartum (+0.9%), but from 6 months to 12 months postpartum no difference was observed. In addition, a 1% higher fat percentage was observed starting from six weeks postpartum onwards among women with a boy, but no difference in the monthly evolution was found for fat percentage.

Multiparous women started at six weeks postpartum with a slightly lower % GWGL (–8%) than primiparous women, regardless of BMI category.

Discussion

This study described PPWR, % GWGL, fat percentage and waist circumference evolution in the first year after delivery among women with preceding excessive GWG and revealed how these evolutions were different according to pre-pregnancy BMI, amount of excessive GWG, and sex of the infant. In terms of lifestyle behaviors, sedentary time was associated with fat percentage, emotional eating with all outcomes, and uncontrolled eating with all outcomes except waist circumference. Additionally, initiation of exclusive breastfeeding plays an important role in PPWR and % GWGL among women with overweight and obesity and in fat percentage among women with overweight. Depressive feelings in the past contributed to PPWR and % GWGL among women with obesity and parity to % GWGL among women of all BMIs.

Pre-pregnancy BMI was found to be an important determinant of all four outcomes, stressing the importance of starting pregnancy with a healthy weight as has been previously postulated [39]. Women with overweight and obesity are estimated to have a higher PPWR at 12 months postpartum compared to women with normal weight. Excessive GWG has been previously shown to be an important risk factor for PPWR [5,6]. The current study showed that within a population of women with excessive GWG, the extent to which women exceed the GWG guidelines is a determinant of PPWR. That is, the more women gain in excess of the guideline, the more PPWR they have throughout the first year postpartum. This is likely to result in long-term PPWR and consequently an increased BMI [40]. Kilograms excessive GWG were furthermore associated with higher fat percentage and

higher waist circumference, suggesting that GWG affects long-term adverse body composition and central adiposity, which is unfavorable in the light of long-term weight-related health risks.

Emotional eating and uncontrolled eating behaviors were found to be associated with the postpartum evolution of PPWR, % GWGL, and body composition. This is a novel finding, as no previous studies have investigated emotional and uncontrolled eating in the postpartum context [15]. It is remarkable that eating behaviors were important determinants rather than food intake, as previous studies suggest food intake to play a role in PPWR. However, those studies did not take eating behaviors into account [14,41].

Sedentary behavior was a determinant of fat percentage. In contrast, physical activity did not contribute to any of the models, even though physical activity was previously found to be an important determinant of (postpartum) weight and body composition [13,42]. The current study reinforces the observation that sedentary behavior is an important health determinant [43,44].

Breastfeeding has been previously suggested to affect PPWR and body composition [10,45,46]. The findings of the current study specifically support that initiation of exclusive breastfeeding is a determinant of lower PPWR and fat percentage, albeit only in women with overweight and obesity. In contrast, there was no evidence that breastfeeding duration played a role in PPWR and body composition. This would imply that starting exclusive breastfeeding, regardless of continuation, is most essential for beneficial maternal health outcomes. This is remarkable, as increased energy expenditure is generally considered to be the underlying reason for the association between breastfeeding and PPWR reduction [10,45,46]. It would be expected that duration of breastfeeding plays a role, as longer duration would imply a longer period of exposure to increased energy expenditure. However, it is also suggested that the increased energy expenditure in breastfeeding mothers is counteracted by an increased energy intake. Other unknown mechanisms could then underlie the association between breastfeeding and PPWR and body composition. The association between breastfeeding initiation and lower PPWR and fat percentage was observed in women with overweight and obesity, specifically. This emphasizes the importance of breastfeeding promotion and support in this population, especially because previous studies showed lower breastfeeding initiation among obese women compared to normal weight women [47]. Depression in general populations has been associated with both weight gain and weight loss [48]. In the perinatal context, depression was previously associated with weight gain [49]. Contrastingly, in the current study a history of depressive

feelings was found to be associated with less PPWR and a greater % GWGL among women with obesity. This finding is rather atypical; however, it does emphasize that preconception (mental) health can have an impact in the long run [37,50]. This finding is especially relevant as obese women are at increased risk of depressive symptoms [51]. Future analyses of the INTER-ACT study population will explore these associations more in depth.

Whereas prenatal weight evolution is usually registered by caregivers in most countries, postpartum weight evolution is generally not systematically registered. A lack of insight into postpartum weight progression generates an inability to identify women at risk of long-term weight retention and related complications. The current study showed that women with ≥ 5 kg PPWR at 12 months postpartum had already a higher PPWR at six weeks postpartum compared to women with < 5 kg PPWR at 12 months. This indicates that weight in early postpartum might aid identification of those at greatest risk of long-term PPWR. To this end, weighing could be integrated in the routine appointment at six weeks postpartum. This is also recommended by the American College of Obstetricians and Gynecologists [52].

The findings further suggest that postpartum lifestyle interventions should probably target eating behavior aside from food intake in women with excessive GWG. A focus on psychological support and coping strategies might be needed to improve eating behavior habits [53,54]. Women with an overweight or obese pre-pregnancy BMI need special attention as they have slower progress with PPWR than women with normal weight. In addition, initiation of exclusive breastfeeding should be further encouraged. Furthermore, both pre-pregnancy weight and GWG require optimization to prevent PPWR. This study provided evidence that limiting GWG, even if the guideline threshold of GWG is exceeded, is worthwhile.

Future research should investigate the most suitable approach to improving eating behavior and sedentary behavior among postpartum women with preceding excessive GWG. In addition, it should be investigated whether interventions targeting eating behavior and sedentary behavior aside from food intake and physical activity are effective in reducing PPWR and improving body composition in this population.

A strength of this study is the specific focus on women with previous excessive GWG and the wide range of determinants studied that potentially increase the risk of long-term PPWR within this high-risk population. Furthermore, examining body composition in addition to weight is of added value since it is linked to health outcomes.

However, this study has limitations. The high drop-out rate is a major drawback of this study, even though a reasonably large sample size was sustained. It is possible that women were, at the time of recruitment—two to three days after delivery—optimistic about participation in a postpartum study, which later might have turned out to be unrealistic for them due to the time and energy constraints common in postpartum. Furthermore, the long follow-up and extensive data collection may have placed a burden on participants. However, mixed model analyses were performed, which account for dropout. A second limitation is the relatively high level of education and predominantly white European ethnicity of the current study population. This might have compromised generalizability of the current findings to the general population. A third limitation is the use of a bio-electrical impedance analysis (BIA) device for the measurement of fat percentage. A validation study among postpartum women with overweight and obesity showed that BIA devices might underestimate fat mass when compared to dual energy X-ray absorptiometry. However, multi-frequency BIA devices as used in the current study perform better than single-frequency devices and are suitable to detect changes in fat mass over time [55], which was the purpose of the measurements in the current study. The negative consequences of using a BIA device in this study are therefore minimal.

Conclusion

Within the high-risk group of women with excessive GWG, lifestyle behaviors are associated with long-term evolution of weight and body composition. In particular eating behavior and sedentary behavior, rather than food intake and physical activity, play an important role in postpartum weight and body composition in this population. These lifestyle behaviors at six weeks postpartum continue to be associated with postpartum weight and body composition up to twelve months postpartum. Lifestyle intervention starting as early as six weeks postpartum might therefore potentially have long-term effects. Furthermore, pre-pregnancy BMI played a role in the long-term evolution of weight and body composition, emphasizing the importance of personalized health care.

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Supplementary files

Supplementary Table 3.1. Drop-out analyses

		Dropped out before 12 months postpartum (n = 213)	Followed up until 12 months postpartum (n = 311)	P-value*
Age at birth, mean (SD)		31.5 (4.1)	31.4 (3.7)	0.94
Parity, n (%)	Primiparous	115 (54)	180 (57.9)	0.38
	Multiparous	98 (46)	131 (42.1)	
Sex of infant, n (%)	Boy	120 (56.3)	154 (49.5)	0.12
	Girl	93 (43.7)	157 (50.5)	
Method of conception, n (%)	Spontaneous	192 (90.1)	281 (93.4)	0.19
	ART	21 (9.9)	20 (6.6)	
	Missing	0	10	
Education, n (%)	Up to 18 years of age	75 (36.9) [a]	74 (24.1) [a]	0.003
	Bachelor	77 (37.9)	122 (39.7)	
	Master or higher	51 (25.1) [a]	111 (36.2) [a]	
	Missing	10	4	
Employment status, n (%)	Employed	183 (90.1)	283 (92.2)	0.43
	Unemployed	20 (9.9)	24 (7.8)	
	Missing	10	4	
Ethnicity, n (%)	White European	179 (88.2)	283 (92.2)	0.13
	Other ethnicity	24 (11.8)	24 (7.8)	
	Missing	10	4	
Pre-pregnancy BMI, n (%)	NW	86 (40.4) [a]	170 (54.7) [a]	0.006
	OW	88 (41.3)	99 (31.8)	
	OB	39 (18.3)	42 (13.5)	
Gestational weight gain in kg, median (IQR)	Among NW	19.2 (17-21.1)	19 (17-21)	0.70
	Among OW	17 (14-20)	15 (13-17.1)	0.007
	Among OB	14.5 (12-17)	13.7 (11.9-16)	0.48
Exclusive breastfeeding at 6 weeks PP, n (%)	Yes	100 (49.8)	183 (59.8)	0.03
	No	101 (50.2)	123 (40.2)	
	Missing	12	5	

		Dropped out before 12 months postpartum (n = 213)	Followed up until 12 months postpartum (n = 311)	P-value*
PPWR in kg at 6 weeks PP, mean (SD)	Among NW	7.8 (3.6)	7.7 (4.1)	0.83
	Among OW	6.5 (4.3)	5.9 (4.2)	0.37
	Among OB	6.3 (6.2)	4.2 (3.7)	0.07
History of depressive feelings, n (%)	Yes	42 (21.1)	37 (12.3)	0.009
	No	157 (78.9)	264 (87.7)	
	Missing	14	10	

* P-value for differences between drop-outs and followed-up sample at 12 months postpartum.

[a] Significant differences after Bonferroni correction.

ART = assisted reproductive treatment; BMI = body mass index; NW = normal weight; OB = obesity; OW = overweight; PP = postpartum; PPWR = postpartum weight retention.

Supplementary Table 3.2. Multivariate mixed model of variables at 6 weeks postpartum associated with evolution of PPWR, %GWGL, fat percentage and waist circumference from 6 weeks to 12 months postpartum.

	PPWR in kg (n = 492)			%GWGL (n = 492)			Fat % (n = 471)			Waist circumference in cm (n = 493)		
	B	SE	P-value	B	SE	P-value	B	SE	P-value	B	SE	P-value
Intercept	5.5055	0.3465	<0.001	66.9	1.757	<0.001	30.5038	0.4973	<0.001	81.9283	0.5843	<0.001
Months	-0.5395	0.06641	<0.001	3.245	0.3532	<0.001	-0.5135	0.04591	<0.001	-1.0063	0.07514	<0.001
Monthsminus6*M6	0.2549	0.08724	0.004	-1.246	0.5103	0.02	0.2096	0.06575	0.002	0.4854	0.1116	<0.001
Overweight	-1.5927	0.6882	0.02				5.7105	0.6909	<0.001	5.7585	0.6759	<0.001
Obesity	-3.3951	0.9355	<0.001				8.7648	0.8441	<0.001	16.2521	0.9354	<0.001
Months*overweight	0.3699	0.08533	<0.001	-1.091	0.4646	0.02	0.2607	0.07212	<0.001	0.3920	0.1008	<0.001
Months*obesity	0.6332	0.1190	<0.001	-2.673	0.6698	<0.001	0.4377	0.1045	<0.001	0.4848	0.1409	<0.001
Monthsminus6*M6*overweight	-0.2922	0.1214	0.02	1.247	0.6895	0.07	-0.1889	0.1063	0.08	-0.3088	0.1502	0.04
Monthsminus6*M6*obesity	-0.4462	0.1673	0.008	2.511	0.9651	0.01	-0.2914	0.1500	0.05	-0.3830	0.2092	0.07
Boy							-1.0437	0.3002	<0.001			
Months*boy	-0.1517	0.06048	0.01	0.9461	0.3656	0.01				-0.1742	0.08004	0.03
Monthsminus6*M6*boy	0.2483	0.09726	0.01	-1.381	0.5756	0.02				0.3839	0.1273	0.003
ExcessiveGWG	0.9814	0.06306	<0.001	-2.03	0.2338	<0.001	0.4507	0.07829	<0.001	0.3875	0.07811	<0.001
Months*excessiveGWG	-0.03755	0.007668	<0.001									
Overweight*excessiveGWG	-0.1914	0.08769	0.03				-0.2641	0.1023	0.01			
Obesity*excessiveGWG							-0.2495	0.1267	0.05			
Obesity*depression	-2.3371	1.0229	0.02	17.53	5.163	0.001						
Overweight*breastfeeding	-1.1175	0.5378	0.04	7.916	2.163	<0.001	-1.3133	0.5326	0.01			

	PPWR in kg (n = 492)			%GWGL (n = 492)			Fat % (n = 471)			Waist circumference in cm (n = 493)		
	B	**SE**	**P-value**	**B**	**SE**	**P-value**	**B**	**SE**	**P-value**	**B**	**SE**	**P-value**
Obesity*breastfeeding	-2.1614	0.8893	0.02	14.48	3.07	<0.001						
Multiparity				-8.04	1.603	<0.001						
Sedentarytime							0.000319	0.000127	0.01			
Emotionaleating							0.01883	0.005310	<0.001	0.03112	0.009026	<0.001

GWG = gestational weight gain; M6 = 6 months postpartum; PPWR = postpartum weight retention; %GWGL = percentage gestational weight gain loss

Supplementary Table 3.3. Multivariate mixed model of variables at 6 weeks and 6 months postpartum associated with evolution of PPWR, %GWGL, fat percentage and waist circumference 6 weeks to 12 months postpartum.

	PPWR in kg (n = 353)			%GWGL (n = 353)			Fat % (n = 354)			Waist circumf. in cm (n = 369)		
	B	**SE**	**P-value**	**B**	**SE**	**P-value**	**B**	**SE**	**P-value**	**B**	**SE**	**P-value**
Intercept	5.3419	0.4043	<0.001	0.6728	0.02019	<0.001	30.4290	0.5562	<0.001	81.8438	0.6298	<0.001
Months	-0.5410	0.07004	<0.001	0.03236	0.003742	<0.001	-0.5016	0.04697	<0.001	-0.9889	0.07635	<0.001
Monthsminus6*M6	0.2681	0.09090	0.004	-0.01311	0.005285	0.01	0.1945	0.06682	0.004	0.4618	0.1122	<0.001
Overweight	-1.5280	0.8357	0.07				5.7218	0.8173	<0.001	6.1251	0.7500	<0.001
Obesity	-3.7140	1.2495	0.003				8.8583	0.9801	<0.001	14.6878	1.0267	<0.001
Months*overweight	0.3681	0.09018	<0.001	-0.00972	0.004957	0.05	0.2510	0.07506	0.001	0.3677	0.1044	<0.001
Months*obesity	0.6621	0.1249	<0.001	-0.02951	0.007083	<0.001	0.4760	0.1076	<0.001	0.5416	0.1434	<0.001
Monthsminus6*M6* overweight	-0.3176	0.1256	0.01	0.01315	0.007127	0.07	-0.1898	0.1090	0.08	-0.3058	0.1530	0.05
Monthsminus6*M6* obesity	-0.4858	0.1723	0.005	0.02838	0.009935	0.005	-0.3413	0.1520	0.03	-0.4386	0.2095	0.04
Boy							-1.1399	0.3469	0.001			
Months*boy	-0.1577	0.06483	0.02	0.01067	0.003926	0.007				-0.1805	0.08168	0.03
Monthsminus6*M6* boy	0.2440	0.1019	0.02	-0.01377	0.005964	0.02				0.3946	0.1289	0.002
ExcessiveGWG	1.0109	0.07688	<0.001	-0.01916	0.002934	<0.001	0.4210	0.08914	<0.001	0.3377	0.08858	<0.001
Months*excessive GWG	-0.03956	0.008187	<0.001									
Overweight* excessive GWG	-0.3071	0.1085	0.005				-0.2196	0.1199	0.07			
Obesity*excessive GWG							-0.3153	0.1632	0.05			

	PPWR in kg (n = 353)			%GWGL (n = 353)			Fat % (n = 354)			Waist circumf. in cm (n = 369)		
	B	SE	P-value	B	SE	P-value	B	SE	P-value	B	SE	P-value
Obesity*depression	-3.1860	1.3035	0.02	0.2192	0.06251	<0.001						
Overweight* breastfeeding	-0.6095	0.6858	0.38	0.06743	0.02575	0.009	-1.0562	0.6685	0.12			
Obesity*breast-feeding	-1.7540	1.2027	0.15	0.1474	0.03693	<0.001						
Multiparity				-0.08697	0.01928	<0.001						
Sedentarytime							0.000332	0.000141	0.02			
Emotionaleating							0.01628	0.006149	0.009	0.03297	0.009924	0.001
M6*Δemotionale-ating[1]	0.03927	0.01300	0.003	-0.00241	0.000803	0.003						
M6*over-weight*Δuncon-trolledeating[1]	0.03227	0.01564	0.04	-0.00239	0.000966	0.01	0.02928	0.01045	0.006	0.02730	0.01455	0.06

GWG = gestational weight gain; M6 = 6 months postpartum; PPWR = postpartum weight retention; %GWGL = percentage gestational weight gain loss.

[1] Change between 6 weeks and 6 months postpartum

Supplementary File 3.1. Example cases to illustrate Table 3.3

To illustrate Table 3.3, two fictive postpartum women are compared, 'A' and 'B'. Both women A and B had a normal weight pre-pregnancy BMI, gave birth to a girl (reference), started exclusive breastfeeding, had no history of depression (reference), and were primiparous (reference). However, woman A and woman B differ in terms of kilograms of excessive weight gain in pregnancy, sedentary time and emotional eating score. Woman A gained 2 kg's in excess of the GWG guidelines, reported sitting 4 hours per day, and had an emotional eating score of 11. Woman B gained 6 kg's in excess of the GWG guidelines, reported sitting 8 hours per day, and had an emotional eating score of 56.
The evolution of PPWR for woman A is calculated as follows:

- Starting point at six weeks postpartum:
  5.5 kg [for normal pre-pregnancy BMI] + 1 kg * 2 [for 2 kg EGWG] = 7.5 kg
- Monthly evolution from six weeks to six months postpartum:
  -0.5 kg [for normal pre-pregnancy BMI] -0.04 kg * 2 [for 2 kg EGWG] = -0.58 kg per month
- Monthly evolution from six months to twelve months postpartum:
  -0.3 kg [for normal pre-pregnancy BMI] -0.04 kg * 2 [for 2 kg EGWG] = -0.38 kg per month

The evolution of PPWR for woman B would be calculated as follows:

- Starting point at six weeks postpartum:
  5.5 kg [for normal pre-pregnancy BMI] + 1 kg * 6 [for 6 kg EGWG] = 11.5 kg
- Monthly evolution from six weeks to six months postpartum:
  -0.5 kg [for normal pre-pregnancy BMI] -0.04 kg * 6 [for 6 kg EGWG] = -0.74 kg per month
- Monthly evolution from six months to twelve months postpartum:
  -0.3 kg [for normal pre-pregnancy BMI] -0.04 kg * 6 [for kg EGWG] = -0.54 kg per month

Figure 3.3 displays the expected PPWR of woman A and woman B based on these calculations.

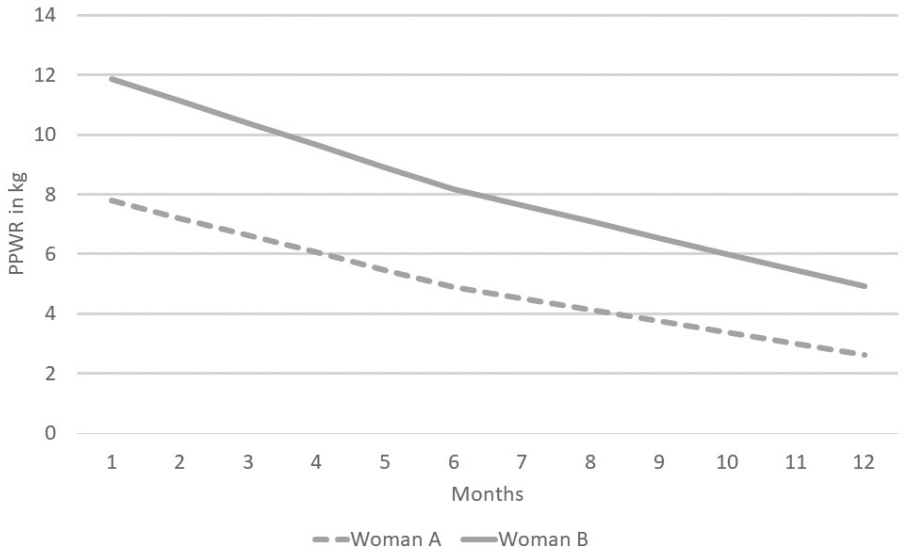

Figure 3.3. Evolution of PPWR in the first year postpartum for example cases A and B

Sedentary time, emotional eating score and starting exclusive breastfeeding did not significantly contribute to the model for PPWR and did thus not play a role in this calculation. However, sedentary time and emotional eating score did contribute to the model for fat percentage.

The evolution of fat percentage for woman A is calculated as follows:

- Starting point at six weeks postpartum:
  30.5 [for normal pre-pregnancy BMI] + 0.5 * 2 [for 2 kg EGWG] + 0.1 * 4 [for 4 sedentary hours per day] + 0.2 * 1.1 [for an emotional eating score of 11] = 32.12 %
- Monthly evolution from six weeks to six months postpartum:
  -0.5 % [for normal pre-pregnancy BMI]
- Monthly evolution from six months to twelve months postpartum:
  -0.3 % [for normal pre-pregnancy BMI]

The evolution of fat percentage for woman B is calculated as follows:

- Starting point at six weeks postpartum:
  30.5 [for normal pre-pregnancy BMI] + 0.5 * 6 [for 6 kg EGWG] + 0.1 * 8 [for 8 sedentary hours per day] + 0.2 * 5.6 [for an emotional eating score of 56] = 35.42 %
- Monthly evolution from six weeks to six months postpartum:
  -0.5 % [for normal pre-pregnancy BMI]
- Monthly evolution from six months to twelve months postpartum:
  -0.3 % [for normal pre-pregnancy BMI]

Besides pre-pregnancy BMI, none of the other variables significantly contributed to the slope of the monthly evolution in the model for fat percentage. Figure 3.4 displays the expected evolution of fat percentage of woman A and woman B based on these calculations.

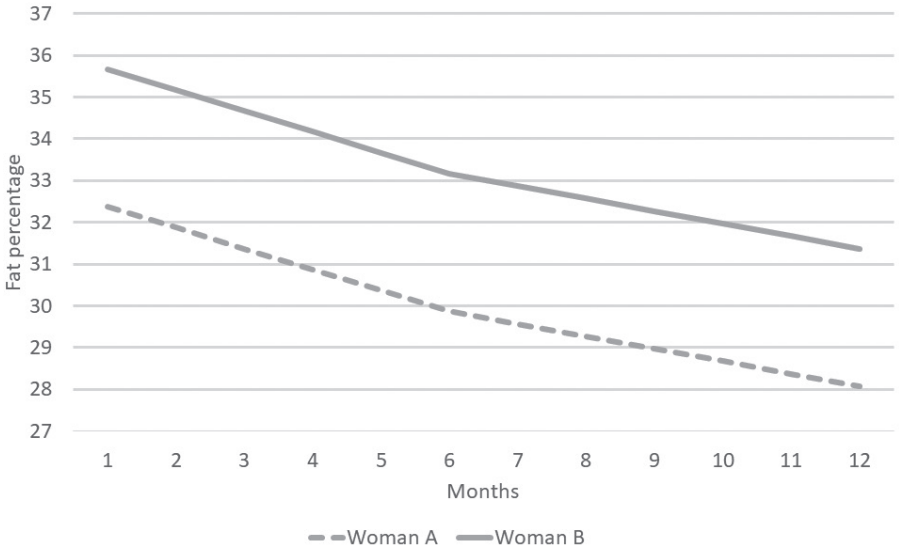

Figure 3.4. Evolution of fat percentage in the first year postpartum for example cases A and B



CHAPTER 4.

Phase angle and bio-impedance values during the first year after delivery in women with previous excessive gestational weight gain

Innovative data from the Belgian INTER-ACT study

Bijlholt, M.*, Maslin, K.*, Ameye, L., Shawe, J., Bogaerts, A., & Devlieger, R. (2021).
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Abstract

Phase angle (PhA) is a body composition parameter that measures changes in the amount and quality of soft tissue. Few studies have explored PhA in pregnancy or postpartum. The aim of this study was to explore the PhA during the first year postpartum in a Belgian cohort using data from the control group of the INTER-ACT study, an intervention trial targeting those with excess gestational weight gain. A secondary aim was to examine associations between PhA and potential explanatory variables. Women aged ≥18 with excessive weight gain in a singleton pregnancy and without a chronic disease were eligible. Data collection included anthropometry as well as demographic and lifestyle questionnaires at 6 weeks, 6 months and 12 months postpartum. Body composition, including PhA, was measured with the Tanita MC780SMA device. Data was analysed using correlation and mixed model analyses. A total of 509 participants (median age 31.2) were included. The median PhA at 6 weeks postpartum was 5.8°. Higher PhA values were seen in multiparous women ($p = 0.02$) but there was no association with any other lifestyle or demographic factors. PhA values were positively associated with muscle mass and BMI ($r = 0.13$, $p = 0.004$ and $r = 0.18$, $p < 0.001$) at 6 weeks postpartum. PhA increased slightly in the 12 months postpartum, which was related to a decrease in fat percentage ($p = 0.004$). Further research in the pregnant/postpartum population is needed to elucidate any links with perinatal or future health outcomes.

Introduction

During pregnancy and postpartum, the female body undergoes significant changes in order to support fetal and infant growth, development and lactation. These changes in lean mass, fat mass and weight are characterised by growth and increases in placental tissue, the uterus, blood volume and amniotic fluid, alongside changes in maternal body fat, breast tissue and total body water [1]. Recommendations for appropriate gestational weight gain (GWG), established by the National Academy of Medicine in 2009, are based on prepregnancy body mass index (BMI), with those who start pregnancy in the overweight or obese categories being advised to gain less weight than those in the healthy weight or underweight categories [2]. Both excess and inadequate GWG are linked to adverse outcomes, such as preterm birth, infant death and offspring weight status in childhood [3–6]. Excess GWG is also associated with postpartum weight retention persisting up to 15 years later [7]. Additionally, weight retention between the first and second pregnancy is associated with an increased risk for perinatal complications, with a greater risk observed in women who were of a healthy BMI in the first pregnancy [8–10].

Although the measurements of weight, height and BMI are simple and practical measurements to undertake in routine clinical practice, BMI does not distinguish between the proportions of lean mass, fat mass or total body water. There is therefore a valid argument for considering alternative measurements, particularly during pregnancy and postpartum. Although imaging methods are considered the most accurate for quantifying fat and lean mass, they are costly, not routinely available and/or are contraindicated due to radiation exposure [11]. In contrast, bioelectrical impedance analysis (BIA) is a low-cost, portable, non-invasive and practical body composition methodology for measuring total body water and body composition [12,13]. BIA is the degree to which a single or multiple currents are slowed (resistance) or stopped (reactance) as it passes through the body. The electrical conductivity of different biological tissues is determined by the amount of water they contain [12].

Phase angle (PhA) is a BIA parameter that was shown to be highly predictive of clinical prognosis and morbidity in a number of disease states [13,14]. PhA measures changes in the amount and quality of soft tissue mass [14]. It is an indicator of the distribution of body water between intra- and extracellular spaces, with higher values reflecting higher cellularity, membrane integrity and better cell function [13]. PhA is affected by age, gender and BMI, with considerable differences between reference values from different

populations [13,14]. It is therefore recommended that individual results should be compared against population-specific reference values [1].

Looking specifically at the measurement of PhA in pregnancy or postpartum, only a few studies have sought to establish reference values [1] and/or explored changes in PhA over time in relation to other body composition variables [15–17]. These results are not externally generalisable as the studies have had small sample sizes [15,16] or described women who were predominantly underweight [17]. Therefore, the aim of this study was to describe and explore the evolution of PhA during the first year postpartum in a Belgian cohort of women who had excess GWG. A secondary aim was to examine associations between PhA, BMI and potential explanatory variables during the first year postpartum.

Materials and methods

Recruitment

This study used data from the INTER-ACT study, an e-health-driven multicentre randomised controlled intervention trial targeting women who had excessive GWG [18,19]. Details of the INTER-ACT protocol and eligibility criteria were previously published [19]. In brief, women aged ≥ 18 years with a history of excessive GWG in a singleton pregnancy were recruited for the study at day 2 or 3 postpartum and randomised to the intervention or control arm of the study at 6 weeks postpartum. Recruitment took place between May 2017 and April 2019. For this analysis, data was only included for participants randomised to the control group.

Data collection included anthropometric and blood pressure measurements (see below for details), as well as demographic and lifestyle questionnaires, which were collected at 6 weeks, 6 months and 12 months postpartum [19]. Pregnancy data and medical history were also collected at recruitment. Pre-existing maternal diseases that possibly affect BIA, such as type I or II diabetes or renal disease, were exclusion criteria.

Anthropometric measurements

The anthropometric data consisted of maternal weight, height, waist and hip circumference and body composition measured using BIA. Maternal height was measured using a Seca–213 Leicester stadiometer (Seca GmbH & Co. KG., Hamburg, Germany). Maternal weight and body composition (fat mass, fat-free mass, muscle mass, total body water, extra-cellular water, intra-cellular water, organ fat and phase angle) were measured with the Tanita MC

780 SMA bio-electric impedance analysis device (Tanita Corporation, Tokyo, Japan). Waist and hip circumferences were measured with a Seca 201 (Seca GmbH & Co. KG., Hamburg, Germany) measuring tape in order to estimate the abdominal body fat. All measurements were performed according to the standard operating procedures to ensure data quality [19].

Measurement of BIA and calculation of phase angle

A multi-frequency BIA device (Tanita MC780) (Tanita Corporation, Tokyo, Japan) was used in this study. This instrument applies alternating currents at 5, 50 and 250 kHz to measure resistance (R), reactance (Xc) and PhA. After entering details on gender, age and height, each participant stepped on the scale platform in light clothing and barefoot with feet on the four integrated electrodes. Grips with integrated electrodes were held in both hands and their arms were in a relaxed position alongside the body. Each measurement took approximately 20 s.

The resulting measurements were automatically transferred to a computer, where they were interpreted by the software. Resistance (R) and reactance (Xc) were expressed as denominators in relation to height-squared [15,17]. Impedance (Z) and phase angle (PhA) were calculated using the formulae: $Z2 = R2 + Xc2$ and $PhA = \arctan(Xc/R)$ for each time point.

Questionnaire data

Two weeks in advance of every measurement appointment, participants received a personalised link to an online questionnaire. Sociodemographic information was only collected in the first questionnaire. A food frequency questionnaire (FFQ) comprising 48 food groups was included and used to calculate daily energy intake in kilocalories [20]. The International Physical Activity Questionnaire (IPAQ) was used to collect data on physical activity expressed as metabolic equivalent of task (MET) minutes per week and sedentary time in minutes per day [21].

Data analysis

Data were analysed using SPSS version 27 (IBM Corporation, Armonk, New York, USA) and SAS version 9.4 (SAS Institute, Cary, North Carolina, USA). Participants with a pre-pregnancy BMI in the underweight range were excluded from the current analyses due to a low number. Measurements taken during a new pregnancy were also excluded from the current analyses. Participant characteristics were presented as number and percentage for categorical variables and median and interquartile range for continuous

variables. In order to assess the association at 6 weeks postpartum (baseline) between the phase angle versus socio-demographic, weight-related and lifestyle determinants, the Spearman correlation was used for the continuous variables and the Wilcoxon test was used for categorical variables. In order to visualise the evolution over time of the phase angle during the first year postpartum, we used a scatterplot with lowess smoothing. In order to assess the evolution over time of the phase angle during the first year postpartum, mixed model analyses with a random intercept, random slope and unstructured working correlation matrix were performed.

Results

Participant characteristics

A total of 509 participants were eligible for inclusion in the current analyses. Figure 4.1 shows the participant flowchart and Table 4.1 shows the baseline characteristics. PhA was not measured in 15 participants. The numbers of participants who withdrew consent and were lost to follow-up at each time point can be seen in Figure 4.1. Participants had a median age of 31 years, 56% were primiparous and 52% gave birth to a boy. The vast majority of participants were of white European descent (91%).

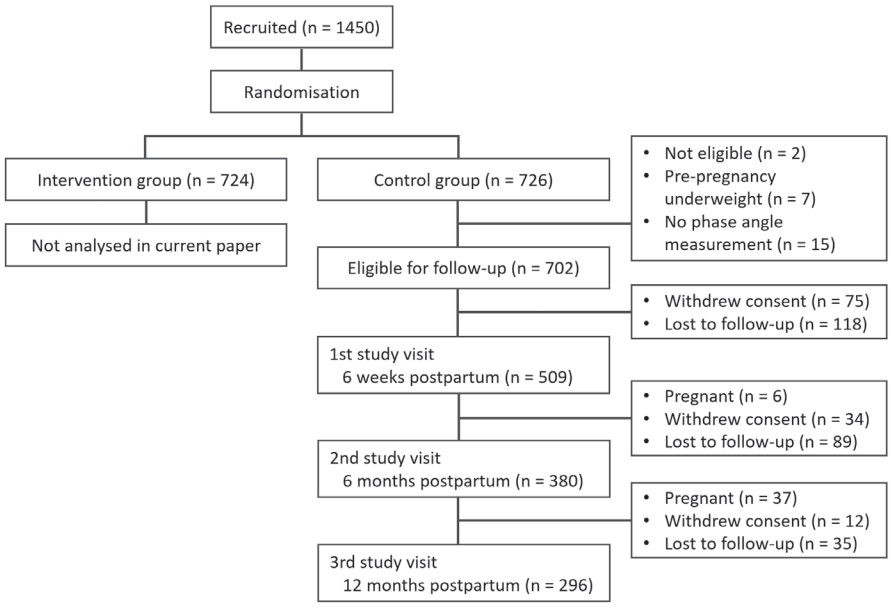

Figure 4.1. Flowchart of participant follow-ups.

Phase angle values at 6 weeks postpartum

Table 4.2 shows the association of the participants' characteristics to the PhA at 6 weeks postpartum. Higher PhA values were associated with higher values of muscle mass and BMI: correlations of 0.13 ($p = 0.004$) and 0.18 ($p < 0.001$), respectively. Please note, muscle mass and BMI were highly correlated: correlation of 0.61 ($p < 0.001$). There was no statistical evidence for an association between PhA and fat percentage ($p = 0.36$), although there seems to be an association between PhA and waist–hip ratio: correlation of 0.16 ($p < 0.001$). Higher PhA values were seen in multiparous women ($p = 0.02$). There was no association between PhA and any other lifestyle or demographic factor, including exclusive breastfeeding status.

Table 4.1. Participant baseline characteristics.

		***n* = 509**
Age at delivery, median (IQR)		31.2 (28.9–33.8)
Parity, *n* (%)	Primiparous	287 (56.4)
	Multiparous	222 (43.6)
Sex of infant, *n* (%)	Boy	266 (52.3)
	Girl	243 (47.7)
Education, *n* (%)	Up to 18 years of age	146 (29.4)
	Bachelor's	194 (39.1)
	Master's or higher	156 (31.5)
	Missing	13
Ethnicity, *n* (%)	White European	450 (90.7)
	Other ethnicity	46 (9.3)
	Missing	13
Pre-pregnancy BMI, *n* (%)	Healthy weight	251 (49.3)
	Overweight	179 (35.2)
	Obesity	79 (15.5)
Gestational weight gain in kg, median (IQR)	Overall	17 (15–20)
	Healthy weight pre-pregnancy	19 (17–21)
	Overweight pre-pregnancy	16 (13–19)
	Obese pre-pregnancy	13.4 (12–17)

		***n* = 509**
PPWR at 6 weeks PP, median (IQR)	Overall	6.5 (3.9–9.0)
	Healthy weight pre-pregnancy	7.4 (5.2–9.6)
	Overweight pre-pregnancy	5.8 (3.2–8.4)
	Obese pre-pregnancy	4.4 (1.2–8.0)
BMI at 6 weeks PP, median (IQR)	Overall	27.7 (25.1–30.9)
Fat percentage at 6 weeks PP, median (IQR)	Overall	34.9 (31.9–38.6)
Muscle mass (in kg) at 6 weeks PP, median (IQR))	Overall	47.8 (44.8–51.0)
Waist–hip ratio at 6 weeks PP, median (IQR)	Overall	0.78 (0.75–0.82)
Phase angle (in degrees) at 6 weeks PP, median (IQR)	Overall	5.8 (5.5–6.1)
Energy intake (in kcal) at 6 weeks PP, median (IQR)	Overall	1387 (1132–1646)
MET-minutes per day at 6 weeks PP, median (IQR)	Overall	265 (127–487)
Sedentary time in minutes per day at 6 weeks PP, median (IQR)	Overall	300 (217–411)
Exclusive breastfeeding at 6 weeks PP, *n* (%)	Yes	274 (55.6)
	No	219 (44.4)
	Missing	16

BMI—body mass index; MET—metabolic equivalent of task; PP—postpartum; PPWR—postpartum weight retention.

Table 4.2. Association between phase angle and participant characteristics at 6 weeks postpartum.

		Association with Phase Angle	***p*-Value**
Age (correlation)		0.03	0.45
Parity (median (IQR))	Nulliparous	5.8 (5.5–6.1)	0.02
	Multiparous	5.9 (5.6–6.2)	
Sex of infant (median (IQR))	Boy	5.8 (5.5–6.1)	0.40
	Girl	5.8 (5.5–6.2)	
Education (median (IQR))	Up to 18 years of age	5.8 (5.5–6.3)	0.46
	Bachelor's degree	5.8 (5.5–6.1)	
	Master's degree or higher	5.8 (5.5–6.1)	

		Association with Phase Angle	*p*-Value
Ethnicity (median (IQR))	White European	5.8 (5.5–6.1)	0.87
	Other ethnicity	5.8 (5.5–6.2)	
Body composition (correlation)	BMI	0.18	<0.001
	Fat percentage	−0.04	0.36
	Muscle mass	0.13	0.004
	Waist–hip ratio	0.16	<0.001
Lifestyle factors (correlation):	Energy intake (in kcal)	0.07	0.13
	MET-minutes/week	0.07	0.16
	Sedentary time/day	−0.08	0.12
Exclusive breastfeeding at 6 weeks (median (IQR))	No	5.8 (5.5–6.1)	0.85
	Yes	5.8 (5.5–6.2)	

BMI—body mass index; MET—metabolic equivalent of task

Evolution in phase angle in the first year postpartum

The PhA increased slightly in the first year postpartum by 0.2° in total. The evolution was from a median of 5.8° at 6 weeks postpartum, to over 5.9° at 6 months postpartum, to 6.0° at 12 months postpartum ($p < 0.001$) (Figure 4.2). The slight increase of PhA in the first year postpartum seems to be related to a decrease in fat percentage ($p = 0.004$), but no statistical evidence for an association to the evolution in muscle mass ($p = 0.65$) or waist-to-hip ratio ($p = 0.77$) was found.

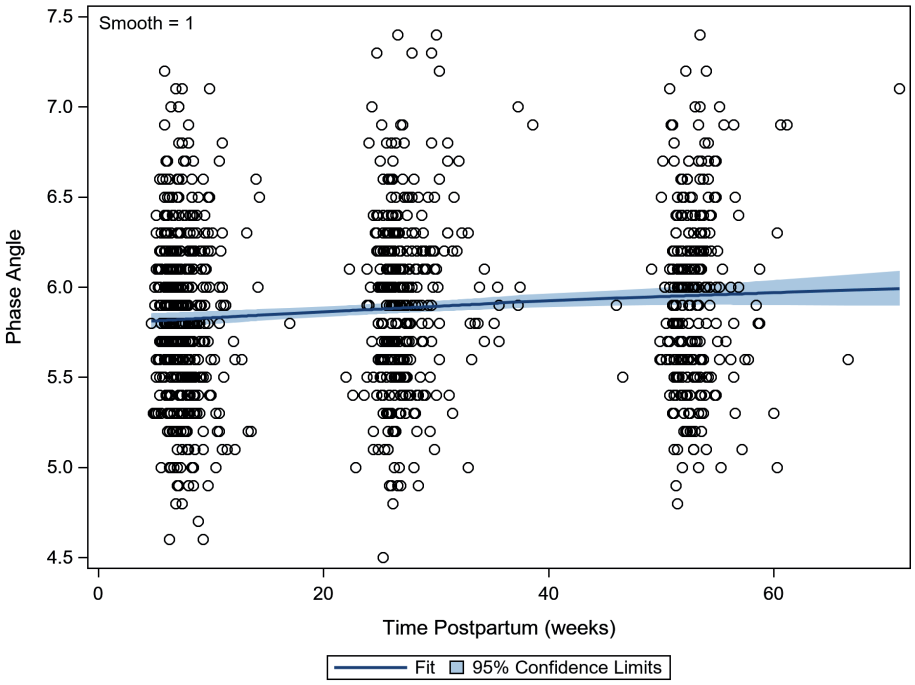

Figure 4.2. Scatterplot of the phase angle in the 1st year postpartum. A lowess smoother (with 95% confidence limits) indicated the evolution over time (lowess—locally weighted scatterplot smoothing).

Discussion

The assessment of changing body composition during pregnancy and lactation is challenging. However, due to the increasing prevalence of maternal obesity and potential obstetric complications, the ability to accurately measure and monitor body composition using simple, reliable and noninvasive methods during this phase is important. This study set out to describe such a method, focusing on the evolution of PhA during the first year postpartum in a Belgian cohort of women. A secondary aim was to examine the associations between PhA, BMI and fat mass percentage during this time. Using a cohort of > 500 women who had excess GWG, at 6 weeks postpartum, PhA was related to muscle mass and BMI, but not to the fat percentage. There was, however, a slight increase in the PhA value during the first year postpartum, which was associated with a decrease in fat percentage. Higher PhA values were linked to higher cellularity, membrane integrity and better cell function.

The association between PhA and muscle mass was previously identified in both clinical and non-clinical populations and is a well-established association [14]. In a study of adults with obesity (60.8% female, mean age of 34.6) [22], PhA was positively correlated with lower- and upper-body maximal strength. Similarly, in malnourished or frail populations, it was found that PhA predicts muscle strength in women with anorexia nervosa [23] and is correlated with gait speed in older women [24]. Our finding that an increase in PhA correlates with a decrease in fat mass concurs with observations from weight loss studies. For example, Gerken et al. [25] identified that preoperative PhA predicts postoperative excess weight loss after bariatric surgery. Many variables, including surgery type, are thought to affect the outcomes of bariatric surgery [26]. Riberio's [27] study in older women with obesity demonstrated decreases in fat mass, in conjunction with increased PhA, after 8 weeks of resistance training. These studies, however, did not address specific changes that occur in body composition that occur after pregnancy, or associated lifestyle factors, such as energy intake or sedentary activity.

Although the above-mentioned studies assessed the association between PhA and fat/muscle mass, few studies were undertaken using PhA in the postpartum population. In a Swedish study of 70 postpartum women, Ellegard et al. [16] reported that PhA was significantly higher at 15 months compared to 3 months postpartum, increasing from 6.33° to 6.44°, in accordance with a decrease in BMI. This concurs with the increase of 0.2° we observed between 6 weeks and 12 months postpartum. Although their sample was very similar to the present study, as measurements were undertaken in a European population of women as part of a lifestyle intervention, their PhA values were higher than we observed. This could be due to the smaller sample size or because their population only included women with overweight and obesity, whereas our inclusion criteria included healthy weight women, albeit with a history of excessive GWG. PhA may also be subject to impedance-analyzer-specific reference values, which depend on the equipment used [14]. The BIA analyzer used in their study underestimated fat mass whilst predicting implausible estimates of muscle mass compared to the double-labelled water method; therefore, their results are not comparable to ours.

After examining other studies of PhA during the postpartum timeframe, Shaikh et al. [17] reported on the evolution of PhA during pregnancy and until 12–18 weeks postpartum in a Bangladeshi population. The PhA in their sample was 6.1° in early pregnancy, decreasing to 5.7° late in pregnancy and increasing again to 5.9° at 12–18 weeks postpartum. Their study population of women was characterised by short stature, low body weight and experiencing their first pregnancy at a young age. Although

the sample size was large, with 1,141 measurements recorded postpartum, the mean BMI was 19.2 (SD 2) kg/m2, which is considered underweight by European standards. Overall, 46.1% of the Bangladeshi cohort were <20 years old at 12–18 weeks postpartum compared to our median age of 31.2 years at delivery. Of note, the authors detected age-related differences in BIA values, whereby PhA was generally lower among adolescents compared to older pregnant women, which is likely attributable to maturational differences of smaller body size and lower lean mass between younger and older women, as younger women grow towards peak stature and fat-free mass. The authors suggest the decrease in PhA in the third trimester, which was not observed in the better-nourished European pregnant populations [1,28], possibly indicates a more compromised body-cell mass profile at the outset of pregnancy and with advancing gestation. It also underlines the fact that BIA values are population-specific [29]. In a small USA-based study of only 15 women who were assessed during each trimester of pregnancy and at 8–10 weeks postpartum, Lukaski et al. [15] found that PhA did not change significantly during pregnancy and postpartum (staying stable at 6.6°). This was despite body weight and total body water (TBW) both progressively increasing during pregnancy and decreasing in the postpartum period, with the authors recommending that impedance vectors can be used to monitor changes in TBW during pregnancy and postpartum. The lack of change in PhA may have been due to the small sample size.

Among non-postpartum populations, Bosy-Westphal et al. [14] reported population reference values for PhA in a large German sample. Depending on BMI and age, the PhA in women of reproductive age ranged from 6.0° to 6.3°, which is slightly higher compared to the PhA values in our postpartum sample. Even higher values were reported among general American and Swiss populations [30,31]. It remains unclear whether the postpartum state of our population is the cause of these lower PhA values or whether these are normal differences observed between populations from different origins.

We investigated the association between PhA at 6 weeks postpartum and several lifestyle factors, namely, energy intake, sedentary activity, physical activity and breastfeeding status, finding no association. We are not aware of other research investigating associations between these parameters and PhA in the postpartum population. A study of Cameroonian women (n = 44) at 2–3 months postpartum found a lack of agreement between four BIA prediction equations. The authors surmised that changes in fat deposition and distribution during lactation or the higher hydration of FFM in lactating women could potentially modify the PhA measurement via the dispersion of the electrical current within the muscles. Previous research

suggests that empirical prediction equations for body composition from BIA may no longer be valid in lactating women, recommending that further development and cross-validation of prediction equations from BIA that are specific to lactating women are needed [29].

At this stage, the precise clinical significance of PhA during the postpartum period is unknown; however, looking more broadly across the clinical nutrition literature, PhA was shown to be predictive of diverse clinical outcomes, including hydration and nutritional status [13,14]. Historically, the applicability of BIA to clinical practice has not been well understood or adopted [32], although in the first instance, establishing normative reference values is required, which we have sought to do in this analysis. The strengths of the study are the large sample size, measurements at multiple time points and robust statistical analyses that took lifestyle factors into account. The limitations are a potential lack of external generalisability due to the fact that only women with previous excess GWG were eligible to take part and the absence of a control group of women with adequate GWG.

Conclusion

In conclusion, we described and derived PhA values in a European cohort of postpartum women, demonstrating that PhA was associated with muscle mass and the increase in PhA during the first year postpartum was related to a decrease in fat percentage. Further research in the pregnant and postpartum population is needed to elucidate any links with perinatal or future health outcomes. Postpartum-specific variables, such as breastfeeding, should be taken into account and women with adequate GWG should be included.

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CHAPTER 5.

The INTER-ACT e-health supported lifestyle intervention improves postpartum food intake and eating behavior, but not physical activity and sedentary behavior

A randomized controlled trial

Bijlholt, M., Ameye, L., Van Uytsel, H., Devlieger, R., & Bogaerts, A. (2021). Nutrients, 13(4), 1287.

Abstract

Unhealthy postpartum lifestyle is related to long-term adverse psychological, metabolic and cardiovascular health outcomes as well as to complications in the next pregnancy. Especially women with preceding excessive gestational weight gain are at risk. This paper aims to evaluate the effect of the postpartum phase of the INTER-ACT randomized controlled trial (RCT) on food intake, eating behavior, physical activity and sedentary time at the end of the intervention (six months postpartum) and at six-months follow-up (12 months postpartum). The study population comprised women with excessive gestational weight gain in the preceding pregnancy. The lifestyle intervention combined a smartphone application with four face-to-face coaching sessions between six weeks and six months postpartum. After the intervention, restrained eating score was 1 point higher (95% CI 0.5, 1.5; $p < 0.001$), uncontrolled eating score was 1 point lower (95% CI -1.9, -0.2; $p = 0.02$) and energy intake was 69 kcal lower (95% CI -123, -15; $p = 0.01$) in the intervention group compared to the control group. The differences were no longer statistically significant at follow-up. No significant effects on emotional eating, physical activity and sedentary behavior were found. In conclusion, the postpartum phase of the INTER-ACT RCT was effective in improving nutrition-related outcomes, however, these improvements could not be sustained at follow-up.

Introduction

Unhealthy lifestyle patterns in the postpartum period are related to adverse psychological, metabolic, and cardiovascular health outcomes in later life for both the mother as well as the child [1–5]. Postpartum weight retention is a potential consequence of unfavorable lifestyle and, in turn, contributes to an increased risk of adverse pregnancy outcomes in a subsequent pregnancy [2,6–8]. Especially women who had excessive weight gain in the preceding pregnancy are at increased risk of postpartum weight retention and therefore of complications in the next pregnancy [9]. Excessive gestational weight gain is defined by the National Academy of Medicine as >9 kg gestational weight gain in mothers with an obese BMI at start pregnancy, >11.5 kg in mothers with overweight at start, and >16 kg in mothers with a normal body–mass index (BMI) at the start of pregnancy [10]. Excessive gestational weight gain is a common condition with a prevalence of approximately 35% in Belgian pregnant women and up to 50% in the United States [9,11,12].

Several postpartum lifestyle interventions have been described in the literature, the majority primarily aiming to reduce postpartum weight retention through lifestyle adaptations [13]. Short, intensive interventions that incorporate a diet only or diet and physical activity component seem most effective in reducing postpartum weight retention. Only a minority of studies incorporate e-health components into their interventions, even though this can be an advantageous extension to face-to-face interventions [14]. Besides, it is uncommon in existing interventions to perceive the postpartum period as inter-pregnancy period and intend to use this period as an opportunity to prepare for a healthy preconception phase. Furthermore, none of the studies specifically focus on women who had excessive gestational weight gain in their preceding pregnancy, although special attention on this high-risk group is required [13].

The INTER-ACT randomized controlled trial (RCT) aims to reduce pregnancy complications through an e-health and face-to-face combined lifestyle intervention. The intervention commences as early as the postpartum period of a preceding pregnancy, which is necessary to timely reach at-risk women and prepare for a healthy preconception period of the next pregnancy. The study specifically targets women who had an excessive gestational weight gain in the preceding pregnancy, since these women are at increased risk of pregnancy- and birth related complications in the next pregnancy. The current paper aims to evaluate whether the postpartum phase of the INTER-ACT RCT is effective in improving lifestyle measures, including food intake, eating behavior, physical activity and sedentary time, at the end

of the intervention and at six months follow-up. We hypothesize that the intervention results in a lower energy intake, improved eating behavior, increased physical activity and decreased sedentary time.

Materials and methods

The methodology of the INTER-ACT RCT has been previously described in detail elsewhere [15]. In summary, the intervention group received the postpartum intervention which took place at week 6, 8, 12 and 6 months after delivery. The only difference between intervention and control group in terms of intervention was that the intervention group received the four coaching sessions and the smartphone application, which was not offered to the control group. Baseline and follow-up measurements took place at same time points in both randomized arms, that is, week 6 (baseline measurement), month 6 and month 12 after delivery. The study was conducted according to the guidelines of the Declaration of Helsinki and was approved on 9 March 2017 by the Ethics Committees of the participating hospitals (protocol code B322201730956). The study was pre-registered on ClinicalTrials.gov (NCT02989142).

Participants

Participants were recruited in six hospitals in the region of Flanders, Belgium: University Hospital Leuven, University Hospital Antwerp, Gasthuiszusters Hospitals Antwerp, Jessa Hospital in Hasselt, Hospital Oost-Limburg in Genk, and Sint-Franciscus Hospital in Heusden-Zolder. Between May 2017 and April 2019, research midwives approached potential participants two to three days after delivery in the hospital. They recruited women with excessive gestational weight gain as defined by the National Academy of Medicine [10]. Women aged 18 or older with a sufficient command of the Dutch language were eligible for enrolment. Women who gave birth to twins, had a stillbirth, previously had bariatric surgery or planned one, or had a chronic or psychiatric disorder were ineligible. All participants provided informed consent upon recruitment.

Due to small numbers, women with pre-pregnancy underweight were excluded from the current analyses (n = 16). Women who got pregnant again within the first year postpartum were excluded from the current analyses from that time point onwards (n = 9 excluded from end of intervention and n = 77 excluded from follow-up analyses).

Randomization

Participants were randomized into the intervention group or control group with an allocation ratio 1:1. The randomization algorithm available in the electronic case report form (eCRF) Castor was used—block randomization with block sizes 4, 6 and 8. At every block generation moment, one of the three block sizes was randomly selected. When a record was randomized, the allocation was randomly selected from the current block in use. The randomization was stratified by hospital. Participants were enrolled by research midwives, and randomized was performed by the biostatistician within the 1st week postpartum. Due to the nature of the intervention, participants and study personnel could not be blinded for randomization. All caregivers involved in the perinatal care path were blinded for the allocation of a specific woman.

Intervention

The lifestyle intervention focused on nutrition, eating behavior, physical activity, sedentary behavior and mental wellbeing delivered by a combination of face-to-face coaching and purpose-designed smartphone application [16].

Coaching sessions took place at 6 weeks, 8 weeks, 12 weeks and 6 months after delivery. For organizational reasons, a range of two weeks before to four weeks after these time points was allowed. A second intervention phase was initiated when participants conceived again, however, the current paper only focuses on the postpartum phase of the intervention. A manual was developed in order to enhance similar implementation of the coaching sessions between the different coaches and coaches received a three-day training session. Motivational interviewing, behavioral change techniques, goal setting, action planning and reinforcement were implemented in the coaching sessions. As to the preference of the participants, coaching sessions took place individually or in small groups of a maximum of three participants.

The smartphone application was installed on the participant's phone at six weeks postpartum and supported the coaching sessions throughout the intervention. Participants who did not own a smartphone received one. Motivational messages and informational tips were sent through the application and participants could set and monitor their own lifestyle goals. Furthermore, the application connected with an activity tracker (Withings GO) and weighing scale (Withings Body+, Withings, Issy-les-Moulineaux, France) that were provided to the intervention group participants to stimulate self-monitoring of physical activity and body weight. The development process and field evaluation of the smartphone application are previously described in detail elsewhere [16].

Data collection

All data were captured in the eCRF Castor. Medical record data was collected upon recruitment by the research midwives. Data on lifestyle behaviors were collected at six weeks postpartum (baseline), six months postpartum (end of intervention) and twelve months postpartum (six-month follow-up) by means of an online questionnaire emailed to the participants. Sociodemographic information was only collected once at baseline.

Data on frequencies and portions of 48 food groups consumed in the past month were collected using a validated food frequency questionnaire [17]. Average daily energy intake was calculated in kilocalories.

Restrained, uncontrolled and emotional eating behaviors were assessed using the Three Factor Eating Questionnaire Revised 18-item version [18]. Restrained eating comprised of six items, uncontrolled eating of nine items, and emotional eating of three items. The items were scored on a four-point Likert scale. Consequently, the possible range of scores were 6–24 for restrained, 9–36 for uncontrolled and 3–12 for emotional eating.

The International Physical Activity Questionnaire was used to assess physical activity in metabolic equivalent of task-minutes (MET-minutes) per week and sedentary time in minutes per day [19]

Data analysis

Data were analyzed for the body mass index (BMI) groups together as well as stratified for normal weight (18.5–24.9 kg/m2), overweight (25.0–29.9 kg/m2) and obesity (30 kg/m2). To assess the effect of the INTER-ACT intervention on eating behavior, food intake, physical activity and sedentary time, univariate analyses were performed using an independent samples t-test for parametric outcome variables and Mann-Whitney U test for non-parametric outcome variables. Multiple linear regression analyses were carried out to adjust for method of conception and kilograms exceeding guidelines of gestational weight gain, which differed between control and intervention group at baseline despite randomization. Results were expressed as mean differences and 95% confidence intervals. MET-minutes for physical activity was non-parametric and was therefore first log-transformed to meet assumptions of multiple linear regression. Emotional eating scores were strongly skewed and transformation of the data did not improve this. Therefore, emotional eating scores were dichotomized into low and high emotional eating based on the median score, and logistic regression was performed to test differences between control group and intervention group. All analyses were performed using SPSS version 26 and SAS version 9.4.

Results

The participant flow is displayed in Figure 5.1. A total of 1450 participants were recruited, of which 726 were randomized into the control group and 724 into the intervention group. At baseline, 524 control group participants and 556 intervention group participants were included in analyses, at end of intervention respectively 390 and 435, and, at six months follow-up, respectively, 288 and 307 participants (Figure 5.1).

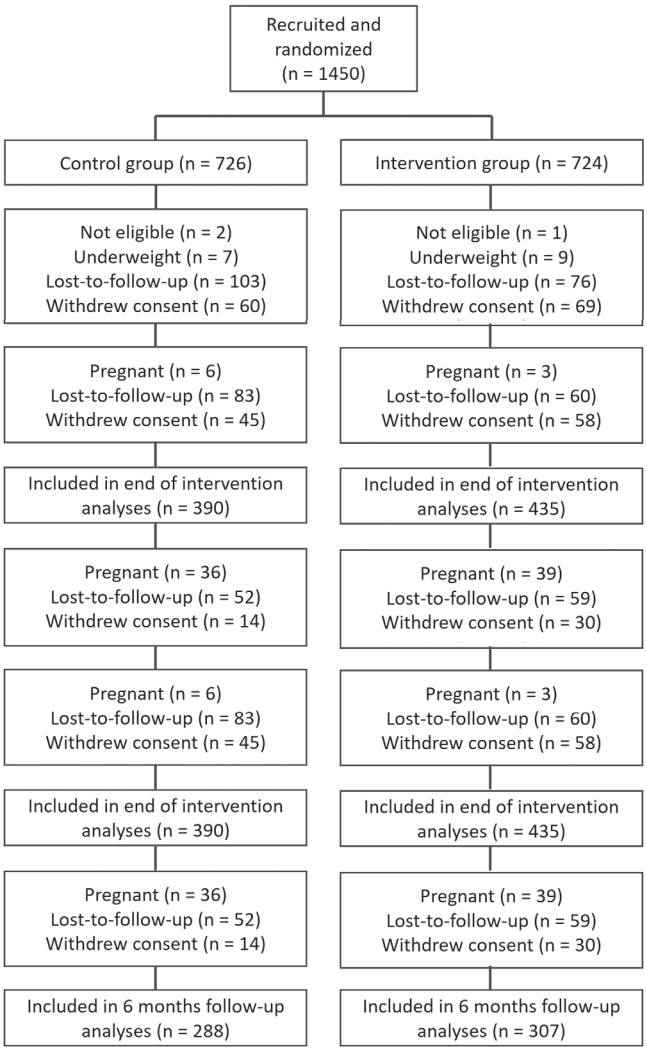

Figure 5.1. Flow chart of participant follow-up

Participants were on average 31.3 years old and no statistical difference was shown with pre-pregnancy BMI category nor with drop-out over time. Half of participants were primiparous (54.8%) and gave birth to a boy (53.4%).

Almost half of the participants had a normal pre-pregnancy BMI (48.6%), 36.0% had a pre-pregnancy BMI in the overweight range, and 15.4% in the obese range (Table 5.1). Despite 1:1 randomization, some significant differences existed between control and intervention group at baseline. More women conceived their pregnancy spontaneously in the control group (92.4%) compared to the intervention group (88.3 percent, $p = 0.03$). Among women with a normal pre-pregnancy BMI, median gestational weight gain was slightly higher in the control group (19 kg, Q1–Q3 17–21 kg) compared to the intervention group (18.2 kg, Q1– Q3 17–20 kg, $p = 0.04$) (Table 5.1). To take these differences into account, the variables were included as covariates in the multivariate regression analyses. All statistically significant differences that were found between control and intervention group in the univariate analyses remained significant after adjusting for kilograms of excessive weight gain and method of conception in the multivariate analyses, indicating that these covariates did not influence the results (Table 5.2).

Eating behavior and food intake

At the end of the intervention (6 months postpartum), restrained eating score was one point higher (95% CI 0.5, 1.5; $p < 0.001$), uncontrolled eating score was one point lower (95% CI 1.9, 0.2; $p = 0.02$) and energy intake was 69 kcal lower (95% CI 123, 15; $p = 0.01$) in the intervention group compared to the control group. Stratification of the BMI groups showed that significant differences between control and intervention group in restrained eating and uncontrolled eating were specifically found in women with normal pre-pregnancy weight (respectively, 1.4 points higher; 95% CI 0.6, 2.1; $p < 0.001$ and 1.6 points lower; 95% CI 2.7, 0.5; $p = 0.004$), and differences in energy intake were specifically seen in participants with an obese pre-pregnancy BMI (174 kcal lower; 95% CI 314, 35; $p = 0.01$). A similar trend of lower energy intake was observed in the other BMI groups as well, although non-significant. No statistical evidence was found for differences in emotional eating between control group and intervention group participants at any of the study measurement points, neither could a clear trend be distinguished (Table 5.2).

At six months follow-up, restrained eating did no longer significantly differ between control group and intervention group, although the difference within the normal weight stratum remained (1.3 points higher in the intervention group; 95% CI 0.5, 2.1; $p = 0.001$). The difference in uncontrolled eating score

also faded at six months follow-up. However, within the overweight BMI stratum, the intervention group had 2.2 points higher uncontrolled eating scores compared to the control group (95% CI 0.7, 3.7; p = 0.006). In the normal weight and obese BMI groups, a trend was observed of lower uncontrolled eating scores in the intervention group compared to the control group, yet not statistically significant. Energy intake remained 138 kcal lower in the obese stratum of the intervention group, although the difference with the control group was no longer significant (p = 0.09) (Table 5.2).

Physical activity and sedentary time

Women with overweight in the intervention group had a borderline non-significantly higher physical activity compared to women with overweight in the control group at follow-up (log of MET-minutes 0.265; 95% CI 0.001, 0.531; p = 0.053). Furthermore, physical activity was generally higher among the intervention group compared to the control group, yet non-significant. Differences were especially large in the subgroup with obesity at end of intervention (3032 MET-minutes per week; 95% CI 2070, 4867 in the intervention group compared to 2491; 95% CI 1167, 5315 in the control group, p = 0.30) and at follow-up (3236 MET-minutes per week; 95% CI 1789, 5412 in the intervention group compared to 2255; 95% CI 960–4576 in the control group, p = 0.06) (Table 5.2). No statistical evidence was found for differences in sedentary time between control group and intervention group participants at any of the study measurement points, although a trend was observed of lower sedentary time in the intervention group compared to the control group (Table 5.2).

Table 5.1. Characteristics of the INTER-ACT participants.

	Overall N = 1046	**Control group N = 504**	**Intervention group N = 542**
Age, mean (SD)	31.3 (3.9)	31.4 (3.8)	31.2 (3.9)
Highest education, n (percent)			
Up to secondary education	296 (28.4)	144 (28.8)	152 (28.1)
College	405 (38.9)	196 (39.2)	209 (38.6)
University	340 (32.7)	160 (32)	180 (33.3)
Missing	5	4	1
Parity, n (percent)			
Primiparous	577 (55.2)	286 (56.7)	291 (53.7)
Multiparous	469 (44.8)	218 (43.3)	251 (46.3)
Sex of infant, n (percent)			
Boy	554 (53)	263 (52.2)	291 (53.7)
Girl	492 (47)	241 (47.8)	251 (46.3)
Method of conception, n (percent) [a]			
Spontaneous	918 (90.1)	455 (92.1)	463 (88.2)
Assisted reproductive technology	101 (9.9)	39 (7.9)	62 (11.8)
Missing	27	10	17
Pre-pregnancy BMI category, n (percent)			
Normal weight	509 (48.7)	249 (49.4)	260 (48)
Overweight	374 (35.8)	181 (35.9)	193 (35.6)
Obesity	163 (15.6)	74 (14.7)	89 (16.4)
Gestational weight gain in kg, median (IQR)			
Among normal weight [b]	18.5 (17-20.9)	19 (17-21)	18 (17-20)
Among overweight	16 (13.5-19)	16 (13-18.9)	16 (14-19)
Among obese	14 (12-17)	14 (12-17)	14 (11.3-17)

[a] Statistically significant difference between control and intervention group (P=0.04)

[b] Statistically significant difference between control and intervention group (P=0.03)

Table 5.2. Univariate and multivariate analyses of the effect of the INTER-ACT randomized controlled trial on lifestyle behaviors.

Outcome	Time point	BMI group [a]	Univariate analyses					Multivariate analyses		
			Control group		Intervention group					
			N	Mean (SD), Median (Q1-Q3) or n (%)	N	Mean (SD), Median (Q1-Q3) or n (%)	P-value [b]	N	Mean difference (95% CI) or OR (95% CI)	P-value [c]
Restrained eating	Baseline (6 weeks PP)	Overall	513	13.4 (3.4)	550	13.3 (3.3)				
		NW	252	13.6 (3.6)	259	13.5 (3.3)				
		OW	188	13.3 (3.1)	200	13.1 (3.3)				
		OB	73	13.3 (3.2)	91	13.3 (3.1)				
	End of intervention (6 months PP)	Overall	377	14.3 (3.5)	374	15.3 (3.5)	<0.001	729	1.0 (0.5 to 1.5)	<0.001
		NW	199	14.1 (3.8)	187	15.4 (3.7)	0.001	375	1.4 (0.6 to 2.1)	<0.001
		OW	125	14.7 (3.1)	137	15.2 (3.5)	0.19	253	0.5 (-0.3 to 1.3)	0.23
		OB	53	14.1 (3.3)	50	15.2 (3.3)	0.08	96	0.4 (-0.8 to 1.6)	0.54
	6-month follow-up (12 months PP)	Overall	285	14.5 (3.6)	276	14.8 (3.2)	0.19	558	0.5 (-0.1 to 1.1)	0.10
		NW	148	14.0 (3.7)	133	14.9 (3.2)	0.04	268	1.3 (0.5 to 2.1)	0.001
		OW	99	14.9 (3.2)	110	14.7 (3.3)	0.77	203	0.0 (-0.9 to 0.9)	0.97
		OB	38	15.3 (4.1)	33	15.2 (3.3)	0.85	68	-0.3 (-2.1 to 1.5)	0.73

Outcome	Time point	BMI group [a]	Univariate analyses					Multivariate analyses		
			Control group		Intervention group					
			N	Mean (SD), Median (Q1-Q3) or n (%)	N	Mean (SD), Median (Q1-Q3) or n (%)	P-value [b]	N	Mean difference (95% CI) or OR (95% CI)	P-value [c]
Uncontrolled eating	Baseline (6 weeks PP)	Overall	513	20.2 (5.5)	550	20.4 (5.5)				
		NW	252	19.5 (5.4)	259	19.1 (5.1)				
		OW	188	20.3 (5.4)	200	21.6 (5.6)				
		OB	73	22.5 (5.6)	91	21.7 (5.5)				
	End of intervention (6 months PP)	Overall	377	20.6 (5.9)	374	19.6 (5.6)	0.02	729	-1.0 (-1.9 to -0.2)	0.02
		NW	199	19.8 (5.7)	187	18.1 (5.1)	0.003	375	-1.6 (-2.7 to -0.5)	0.004
		OW	125	20.6 (5.7)	137	20.9 (5.7)	0.67	253	0.13 (-1.3 to 1.6)	0.86 [d]
		OB	53	23.8 (6.1)	50	21.8 (5.8)	0.09	101	-1.6 (-4.0 to 0.8)	0.19
	6-month follow-up (12 months PP)	Overall	286	19.7 (5.6)	276	19.7 (5.7)	0.88	559	0.0 (-0.9 to 0.9)	0.85
		NW	149	19.0 (5.2)	133	18.1 (5.2)	0.18	278	-1.0 (-2.2 to 0.2)	0.09
		OW	99	19.4 (5.3)	110	21.3 (6.1)	0.02	194	2.2 (0.7 to 3.7)	0.006 [d]
		OB	38	23.0 (6.6)	33	21.0 (5.3)	0.18	71	-2.1 (-5.0 to 0.9)	0.18

Outcome	Time point	BMI group [a]	Univariate analyses					Multivariate analyses		
			Control group		Intervention group					
			N	Mean (SD), Median (Q1-Q3) or n (%)	N	Mean (SD), Median (Q1-Q3) or n (%)	P-value [b]	N	Mean difference (95% CI) or OR (95% CI)	P-value [c]
Emotional eating, continuous	Baseline (6 weeks PP)	Overall	513	6.0 (4.0-8.0)	550	6.0 (4.0-9.0)				
		NW	252	5.0 (3.0-8.0)	259	5.0 (3.0-8.0)				
		OW	188	6.0 (5.0-9.0)	200	7.0 (5.0-9.0)				
		OB	73	8.0 (5.5-9.5)	91	8.0 (6.0-10.0)				
	End of intervention (6 months PP)	Overall	377	6.0 (4.0-9.0)	374	6.0 (4.0-9.0)	0.88			
		NW	199	5.0 (3.0-8.0)	187	5.0 (3.0-8.0)	0.83			
		OW	125	6.0 (4.5-9.0)	137	7.0 (4.0-9.0)	0.82			
		OB	53	9.0 (5.0-10.5)	50	8.0 (6.0-10.0)	0.93			
	6-month follow-up (12 months PP)	Overall	286	6.0 (4.0-8.0)	276	6.0 (4.0-9.0)	0.26			
		NW	149	6.0 (4.0-7.0)	133	5.0 (3.0-8.0)	0.50			
		OW	99	7.0 (4.0-9.0)	110	7.0 (5.0-10.0)	0.07			
		OB	38	8.0 (5.0-11.0)	33	8.0 (5.5-9.5)	0.90			

Outcome	Time point	BMI group [a]	Univariate analyses					Multivariate analyses		
			Control group		Intervention group					
			N	Mean (SD), Median (Q1-Q3) or n (%)	N	Mean (SD), Median (Q1-Q3) or n (%)	P-value [b]	N	Mean difference (95% CI) or OR (95% CI)	P-value [c]
High emotional eating (score > 6)	Baseline (6 weeks PP)	Overall	513	221 (43.1%)	550	264 (48.0%)				
		NW	252	84 (33.3%)	259	89 (34.4%)				
		OW	188	90 (47.9%)	200	115 (57.5%)				
		OB	73	47 (64.4%)	91	60 (65.9%)				
	End of intervention (6 months PP)	Overall	377	165 (43.8%)	374	169 (45.2%)	0.70	729	1.04 (0.78 to 1.40)	0.78
		NW	199	68 (34.2%)	187	63 (33.7%)	0.92	375	0.94 (0.61 to 1.45)	0.79
		OW	125	59 (47.2%)	137	73 (53.3%)	0.33	253	1.21 (0.73 to 1.99)	0.46 [e]
		OB	53	38 (71.7%)	50	33 (66%)	0.53	101	0.80 (0.34 to 1.87)	0.60
	6-month follow-up (12 months PP)	Overall	286	128 (44.8%)	276	131 (47.5%)	0.52	559	1.12 (0.80 to 1.56)	0.52
		NW	149	54 (36.2%)	133	46 (34.6%)	0.77	285	0.93 (0.56 to 1.52)	0.76
		OW	99	50 (50.5%)	110	61 (55.5%)	0.47	203	1.18 (0.67 to 2.05)	0.57 [e]
		OB	38	24 (63.2%)	33	24 (72.7%)	0.39	71	1.44 (0.51 to 4.05)	0.49

Outcome	Time point	BMI group [a]	Univariate analyses					Multivariate analyses		
			Control group		Intervention group					
			N	Mean (SD), Median (Q1-Q3) or n (%)	N	Mean (SD), Median (Q1-Q3) or n (%)	P-value [b]	N	Mean difference (95% CI) or OR (95% CI)	P-value [c]
Energy intake (kcal)	Baseline (6 weeks PP)	Overall	517	1399 (378)	553	1409 (414)				
		NW	254	1351 (344)	262	1398 (430)				
		OW	189	1443 (414)	200	1390 (356)				
		OB	74	1448 (376)	91	1482 (475)				
	End of intervention (6 months PP)	Overall	378	1277 (375)	377	1204 (364)	0.006	732	-69 (-123 to -15)	0.01
		NW	199	1249 (381)	189	1199 (390)	0.20	377	-43 (-121 to 36)	0.30
		OW	126	1277 (361)	138	1201 (325)	0.07	254	-75 (-161 to 11)	0.09
		OB	53	1385 (372)	50	1230 (372)	0.04	94	-174 (-314 to -35)	0.01
	6-month follow-up (12 months PP)	Overall	286	1174 (339)	279	1172 (333)	0.95	562	-1 (-62 to 59)	0.96
		NW	149	1139 (324)	135	1146 (313)	0.85	287	15 (-70 to 101)	0.74
		OW	99	1208 (361)	110	1224 (343)	0.75	199	28 (-68 to 125)	0.57
		OB	38	1220 (328)	34	1106 (361)	0.17	69	-138 (-296 to 20)	0.09

Outcome	Time point	BMI group [a]	Univariate analyses					Multivariate analyses		
			Control group		Intervention group					
			N	Mean (SD), Median (Q1-Q3) or n (%)	N	Mean (SD), Median (Q1-Q3) or n (%)	P-value [b]	N	Mean difference (95% CI) or OR (95% CI)	P-value [c]
Physical activity (MET-minutes per week)	Baseline (6 weeks PP)	Overall	487	1857 (891-3438)	533	1728 (920-3279)				
		NW	236	1785 (892-3525)	252	1685 (787-3070)				
		OW	182	1924 (918-3030)	191	1837 (1118-3143)				
		OB	69	1860 (848-3725)	90	1899 (836-3673)				
	End of intervention (6 months PP)	Overall	344	2461 (1342-4691)	340	2640 (1372-5397)	0.40	649	0.052 (-0.099 to 0.203) [f]	0.50
		NW	182	2406 (1372-4595)	168	2634 (1325-5294)	0.65	333	0.062 (-0.145 to 0.270) [f]	0.56
		OW	114	2681 (1319-4593)	131	2547 (1299-5876)	0.98	230	-0.036 (-0.296 to 0.223) [f]	0.78
		OB	48	2491 (1167-5315)	41	3032 (2070-4867)	0.30	75	0.104 (-0.292 to 0.501) [f]	0.60
	6-month follow-up (12 months PP)	Overall	269	2403 (1240-4543)	261	2814 (1501-5312)	0.11	497	0.144 (-0.025 to 0.313) [f]	0.09
		NW	143	2616 (1107-4650)	128	2519 (1392-4103)	0.11	251	-0.018 (-0.256 to 0.220) [f]	0.88
		OW	94	2132 (1417-4072)	101	3210 (1530-6293)	0.70	181	0.265 (-0.001 to 0.531) [f]	0.053
		OB	32	2255 (860-4576)	32	3236 (1789-5412)	0.06	61	0.413 (-0.128 to 0.953) [f]	0.14

Outcome	Time point	BMI group [a]	Univariate analyses					Multivariate analyses		
			Control group		Intervention group					
			N	Mean (SD), Median (Q1-Q3) or n (%)	N	Mean (SD), Median (Q1-Q3) or n (%)	P-value [b]	N	Mean difference (95% CI) or OR (95% CI)	P-value [c]
Sedentary time (minutes per day)	Baseline (6 weeks PP)	Overall	486	325 (171)	532	323 (180)				
		NW	235	325 (183)	252	313 (171)				
		OW	182	324 (151)	191	332 (193)				
		OB	69	326 (180)	89	330 (178)				
	End of intervention (6 months PP)	Overall	343	308 (167)	338	293 (162)	0.21	661	-14 (-39 to 12)	0.30
		NW	182	319 (161)	167	299 (170)	0.26	339	-21 (-57 to 15)	0.26
		OW	113	310 (179)	130	286 (163)	0.28	232	-24 (-65 to 18)	0.29
		OB	48	266 (160)	41	288 (120)	0.46	81	31 (-28 to 90)	0.30
	6-month follow-up (12 months PP)	Overall	269	317 (160)	261	299 (173)	0.22	511	-17 (-46 to 13)	0.28
		NW	143	319 (158)	128	287 (155)	0.09	263	-33 (-72 to 6)	0.12
		OW	94	311 (157)	101	302 (182)	0.74	178	-17 (-61 to 26)	0.43
		OB	32	321 (176)	32	334 (213)	0.79	58	-3 (-90 to 85)	0.95

Abbreviations: MET = metabolic equivalent of task; NW = normal weight; OW = overweight; OB = obesity; PP = postpartum

[a] Pre-pregnancy BMI category

[b] P-value for differences between control group and intervention group, using independent samples t-test, Mann-Whitney U test, or likelihood ratio test.

[c] P-value for difference between groups, adjusted for method of conception and kilograms of excessive weight gain, using multivariate linear or logistic regression.

[d] Post-hoc analyses with baseline uncontrolled eating scores added to the model (due to significant difference at baseline, P=0.02) did not change the results (data not shown).

[e] Post-hoc analyses with baseline percentage of women with high emotional eating score added to the model (due to significant difference at baseline, P=0.05) did not change the results (data not shown).

[f] Log of MET-minutes

Discussion

This paper reports on the first e-health supported randomized controlled trial (RCT) focusing on lifestyle behavior in postpartum women with preceding excessive gestational weight gain. We show that the INTER-ACT postpartum lifestyle intervention is effective in enhancing restrained eating and in reducing both uncontrolled eating and energy intake in this population of women. These changing behaviors are important steps towards promoting a healthy postpartum lifestyle in this high-risk group. A healthier lifestyle has the potential to contribute to better long-term outcomes such as reduced obesity and better pregnancy- and birth related outcomes in a next pregnancy [3,6,8]. The intervention did not significantly affect emotional eating, physical activity and sedentary time.

There is dissent on whether or not an increased restrained eating score is favorable and should be encouraged. On the one hand it is argued that restrained eating contributes to weight loss, potentially mediated by decreased energy intake [3,20–24]. On the contrary, restrained eating is also thought to induce episodes of uncontrolled eating, which could nullify the beneficial effects on energy intake or potentially even result in an increased energy intake [25]. However, it is unlikely that the latter situation applies in the current study population, since simultaneously with the elevated restrained eating score, lower uncontrolled eating scores and energy intake were observed in the intervention group compared to the controls.

Remarkably, our results also revealed that at six months follow-up, uncontrolled eating was higher among intervention participants with overweight compared to controls with overweight, even though scores did not differ at the end of the intervention. This might signify that once the lifestyle intervention is finished, there is a feeling of letting loose that causes a relapse towards old behaviors.

No statistical evidence was found for an intervention effect on physical activity and sedentary time. However, generally a trend was observed of higher physical activity levels in the intervention group compared to controls, yet it was not statistically significant. Previous postpartum interventions did result in significantly increased physical activity [26,27], although not all [28]. Notably, the latter study was a combined lifestyle intervention focusing on both physical activity and nutrition, alike our intervention, whereas the interventions that did effectively increase physical activity had a focus on physical activity alone. This might potentially indicate that combined lifestyle interventions are not the most effective approach when increasing

physical activity is the aim. This should however be further investigated in for example a meta-analysis. Alike physical activity, neither did sedentary time significantly improve in the intervention group compared to controls. This is not surprising due to the early postpartum being principally characterized by sedentariness inherent to infant feeding.

Overall, the current study showed effectiveness, especially in the normal weight subgroup. This is an important finding, as women who had an initial normal weight BMI are prone to shifting to the overweight BMI category between pregnancies [29]. Increasing interpregnancy BMI increases the risk of pregnancy- and birth-related complications in the next pregnancy such as gestational diabetes, pregnancy-induced hypertension, cesarean section, and macrosomia [29]. Improving lifestyle in the postpartum period might prevent this shift to a higher BMI and consequently decrease the risk of pregnancy- and birth related complications in a next pregnancy. A reduction of energy intake that is sustained for a longer period of time can contribute to weight loss and therewith a decreased postpartum weight retention. As the difference in energy intake between intervention and control group in the current study faded at six months follow-up, the intervention might potentially not have sustained long enough to lead to less postpartum weight retention in the intervention group. Future analyses will point out whether the INTER-ACT intervention affects postpartum weight retention after intervention and at follow-up.

Simultaneously, the largest effect sizes for energy intake and physical activity were observed among women with a BMI in the obese range. Physical activity at follow-up was even approximately 40% higher in the intervention group compared to controls. The differences between intervention and control groups were however in most cases not statistically significant, which is probably a result of the relatively small sample size of this BMI stratum. The large effect sizes might indicate that the intervention is in fact appropriate for this subgroup or that women with an obese pre-pregnancy BMI are especially motivated to improve their lifestyle habits in postpartum. This is a potentially important finding since women with obesity are especially at risk of long-term morbidity and passing on an increased risk of obesity to their offspring.

This study is subject to limitations. Firstly, the measurement of the intervention effect coincided with the last coaching session of the intervention group. Consequently, the effects shown here might not represent the full effects, as the effect obtained through this last coaching visit is not captured in the measurement. This might imply that intervention effects were potentially larger in reality, and not fully represented by the current figures.

Secondly, we found a large variation in the App use in the intervention arm: 11% did not use the App at all. If we look at the activity percentage, defined as number of days the app was used, divided by the total number of days between the week 6 and month 6 measurements (i.e., the duration of the intervention), and compare passive to active users (according to their activity percentage), we found that App use was related to the highest degree of education (higher use in university) and composition of the family (higher use in one-parent families). Furthermore, there was no statistical evidence of the activity percentage with ethnicity, employment status, income, number of hours sleep, sleep problems, or breast feeding the baby. Thirdly, the mean energy intake values are very low in both intervention and control group, and across BMI categories. This is likely due to underreporting, which is not uncommon in food frequency questionnaires [30]. Park et al. [30] concluded that average underreporting of absolute energy intake by the Food Frequency Questionnaire (FFQ) compared with an objectively measured energy biomarker, ranged from 25% to 40% and underreporting was more prevalent among obese individuals. This explains the range of a 25% to 40% lower energy intake level as mentioned here, between 1100 to 1400 kcal. As FFQ provides important information about episodically consumed foods, and assuming that the underreporting is systematic, we think that these values do not jeopardize the comparability between intervention and control group, which was the main aim of this paper. However, it might have compromised generalizability and comparability of this study with other studies.

Conclusion

The INTER-ACT lifestyle intervention combines face-to-face coaching with a smartphone application, targeting women with excessive gestational weight gain in the preceding pregnancy. The current analyses revealed that the postpartum phase of this RCT was effective in improving nutrition-related outcomes but not physical activity-related outcomes. The improvements could not be sustained at six months follow-up, and therefore the long-term benefits of the intervention are uncertain.

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CHAPTER 6.

Effect of the e-health supported INTER-ACT lifestyle intervention on postpartum weight retention and body composition, and associations with lifestyle behavior

A randomized controlled trial

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Submitted

Abstract

Background: Women with excessive gestational weight gain (GWG) are at increased risk of postpartum weight retention (PPWR) and long-term obesity.

Objective: To investigate whether the postpartum phase of the INTER-ACT lifestyle intervention reduced PPWR and improved body composition, and whether improved lifestyle was associated with more postpartum weight loss and improved body composition.

Methods: A randomized controlled trial was conducted between 6 weeks and 6 months postpartum among 1075 women with preceding excessive GWG. The intervention comprised four face-to-face coaching sessions combined with a smartphone application.

Results: Weight and body composition did not differ between intervention and control group at 6 months postpartum. Larger decrease in weight was observed among intervention participants who reduced their energy intake (mean ± SD: 3.1 ± 4.2 kg vs. 2.2 ± 3.8 kg, P=0.05) and decreased uncontrolled eating (3.5 ± 4.2 kg vs. 1.9 ± 3.7 kg, P<0.001) by the end of the intervention, compared to those who did not improve. Larger decrease in fat percentage was observed among women who reduced energy intake (2.3% ± 2.9 vs. 1.4% ± 2.7, P=0.01), enhanced restrained eating (2.2% ± 3 vs. 1.4% ± 2.6, P=0.02) and decreased uncontrolled eating (2.3% ± 2.9 vs. 1.5% ± 2.7, P=0.01) compared to those who did not. Larger decrease in waist circumference was observed among women who reduced energy intake (4.6 cm ± 4.8 vs. 3.3 cm ± 4.7, P=0.01), enhanced restrained eating (4.5 cm ± 4.8 vs. 3.4 cm ± 4.8, P=0.05) and decreased uncontrolled eating (4.7 cm ± 4.8 vs. 3.3 cm ± 4.8, P=0.006), compared to those who did not.

Conclusion: The INTER-ACT intervention did not reduce PPWR among women with preceding excessive GWG. Nutrition-related behaviors were associated with weight, fat percentage and waist circumference at 6 months post-delivery.

Introduction

Postpartum weight retention (PPWR) is a risk factor for complications in a subsequent pregnancy, intergenerational obesity, long-term maternal obesity and unfavorable cardiometabolic profile.[1-3] Women with excessive weight gain during pregnancy are at high risk of PPWR.[4] In Flanders, the Northern region of Belgium, one in three women suffers from excessive gestational weight gain (GWG) as defined by the guidelines by the National Academy of Medicine.[5,6] Women with excessive GWG have a twofold increased risk of pregnancy and birth related complications in a subsequent pregnancy[7] and half of the women with excessive GWG turned out to have long-term PPWR (i.e. at age 42-52 or ≥ 15 year post-delivery).[8,9] Despite a multitude of lifestyle intervention initiatives aiming to reduce PPWR, no interventions specifically targeting the high-risk group of women with preceding excessive GWG have been described in literature.[10,11]

Measurement of body composition components provides complementary insight in nutritional and health status beyond weight or BMI. A high percentage of fat mass is associated with increased health risks, even in individuals with a BMI within the normal range.[12,13] Waist circumference is a reliable indicator for abdominal obesity and is therefore a better predictor for health outcomes than BMI.[14] Reference values for waist circumference cannot be applied in early postpartum due to the changed body proportions related to pregnancy. However, monitoring longitudinal changes in waist circumference in the postpartum can be informative.[15]

The INTER-ACT randomized controlled trial (RCT) was designed with the primary aim of reducing pregnancy- and birth related complications. Since these complications are mostly seen in women with excessive GWG in the preceding pregnancy, the intervention specifically targets this risk group. A lifestyle coaching program was provided as early as the postpartum period after the pregnancy with excessive GWG (first intervention phase). Participants were followed up until a subsequent pregnancy, during which a second intervention phase was administered.[16] The intervention focuses on healthy eating, physical activity and mental wellbeing with a motivational interviewing approach. Furthermore, the intervention was provided through blended care: a combination of face-to-face coaching and e-health. This approach has previously been suggested for the reduction of PPWR.[17]

A secondary aim of the INTER-ACT study was to reduce PPWR and improve body composition in the postpartum phase following pregnancy with excessive GWG, i.e. after the first intervention phase. This is evaluated in the

current paper. We hypothesize that women receiving the intervention have less postpartum weight retention and a larger decrease in fat percentage and waist circumference compared to the control group.

We previously showed that the INTER-ACT intervention was effective in improving energy intake and eating behavior.[18] A secondary aim of the current paper was therefore to examine whether improving lifestyle behaviors (i.e. energy intake, eating behavior, physical activity and sedentary behavior) during the postpartum intervention is associated with improved postpartum weight and body composition. We hypothesize that improvement of these lifestyle behaviors post-delivery would improve postpartum weight loss and lead to more favorable body composition.

Methods

The analyses of this paper were performed using data from the INTER-ACT multi-center RCT, which specifically targeted women who had excessive GWG. The methodology used in the INTER-ACT trial is described in detail elsewhere.[16] The current analyses focused on the first phase of the trial: from 6 weeks post-delivery until 6 months post-delivery.

Participants

Women were eligible for participation in the INTER-ACT study if they were ≥18 years of age and had an excessive gestational weight gain according to the 2009 National Academy of Medicine guidelines (>18 kg for women with pre-pregnancy underweight; >16 kg for women with normal weight; > 11.5 kg for women with overweight; >9 kg for women with obesity) during a singleton pregnancy.[6] Women were excluded from participation if they required complex medical diets; if they had a history of bariatric surgery or were planning for one in the near future; if they had chronic disorders such as diabetes mellitus type 2 or significant psychiatric disorders; if they had a stillbirth in the last pregnancy. Participants were excluded from the current analyses if body weight and anthropometrics were missing for both 6 weeks and 6 months postpartum.

Participants were recruited by study midwives in 6 hospitals in the region of Flanders, Belgium: University Hospital Leuven, University Hospital Antwerp, Gasthuiszusters Hospitals Antwerp, St-Franciscus Hospital in Heusden-Zolder, Jessa Hospital in Hasselt, and Hospital Oost-Limburg in Genk. Recruitment took place within the first days after delivery, during hospital admission.

The sample size was calculated based on the primary outcome of the study, a composite outcome of gestational diabetes, pregnancy-induced hypertension, cesarean section and large for gestational age infant at the end of the next pregnancy. Further details on the sample size calculation are described previously in the study protocol.[16]

Randomization

Participants were randomized into the intervention group or control group according to random computerized allocation by the electronic case report form (eCRF) system Castor. Participants were randomized within the first week after recruitment. Randomization was stratified by hospital and a 1:1 allocation ratio using block randomization with block sizes 4, 6 and 8 was applied. The block size was randomly selected at every new block generation. Participants and study personnel could not be blinded for allocation to the intervention or control group due to the nature of the intervention.

Data collection

In both the intervention and control group anthropometric data collection took place at 6 weeks (baseline) and 6 months post-delivery. Data were collected at the home of the participant or at a research location (e.g. hospital, private clinic, children's healthcare center, or university) and were captured in the eCRF Castor.

Age, parity, sex of the infant, pre-pregnancy BMI group and GWG were retrieved from the medical record upon recruitment. Level of education and ethnicity were queried through a questionnaire that was sent to the participants in advance of the baseline appointment.

Height was measured at the baseline appointment only, using a Seca 213 stadiometer and registered to 1 mm accurate. Weight and fat percentage were measured using a Tanita MC 780 SMA bio-electric impedance analysis device with 3 measuring frequencies (5, 50 and 250 kHz). Postpartum weight retention was calculated as the difference between weight at each respective time point and pre-pregnancy weight. Waist and hip circumference were measured using a Seca 201 measuring tape and were registered to 1 mm accurate.

Energy intake was assessed using a validated 24-item Food Frequency Questionnaire.[19] Frequency and amount of intake was queried for every item. Energy intake in kcal was calculated using a predefined syntax. Restrained,

uncontrolled and emotional eating were assessed using the validated Three-Factor Eating Questionnaire Revised 18-item version (TFEQ-R18).[20] Physical activity and sedentary time were assessed using the International Physical Activity Questionnaire (IPAQ).[21] Physical activity in metabolic equivalent of task minutes (MET-minutes) per week and sedentary time in minutes per week were calculated using a predefined syntax.

Intervention

Face-to-face lifestyle coaching sessions took place at approximately 6 weeks, 8 weeks, 12 weeks and 6 months post-delivery. For feasibility, a range of 2 weeks before to 4 weeks after these time points was permitted according to the protocol. The first coaching session at 6 weeks postpartum generally took place at the participant's home. The subsequent sessions took place at the participant's home or at a research location and individually or in small groups of 2 to 3 participants. The coaching sessions were based on the 3 pillars of a healthy lifestyle: healthy eating, physical activity, and mental wellbeing. Motivational interviewing and behavior change techniques had a central role in the sessions. Also, a smartphone application specifically designed for this trial was installed on the participant's smartphone during the first appointment.[22] This application was created in order to support the participants in their behavior change in between the face-to-face coaching sessions up to 6 months postpartum. A Bluetooth connection was set up with an activity tracker (Withings Go) and a weighing scale (Withings Body+). The application facilitated self-monitoring, goal-setting and sent tailored motivational messages.[22]

Control group participants received no intervention.

Data analysis

Variables were tested for normality by visual judgement of the histogram and by using the Shapiro Wilk test. Baseline characteristics were described with n, % for categorical variables and mean ± SD or median (IQR) depending on normality for continuous variables. Differences in PPWR, fat percentage and waist circumference between groups were tested using univariate linear regression analyses. Multivariate analyses using logistic regression were performed to test differences between groups adjusted for maternal age, parity, and weeks between the measurements. For the secondary aim of this paper, intervention group participants were divided into groups of participants who improved and who did not improve lifestyle behaviors. Differences in weight loss and decrease of fat percentage

and waist circumference between groups were tested using univariate linear regression analyses. Improvement of energy intake was defined as a 100 kcal/day decrease during the intervention period. Improvement of restrained eating was defined as a 1-point increase during the intervention period; improvement of uncontrolled and emotional eating were both defined as a 1-point decrease during the intervention period. Rationale is that previous analyses showed that the INTER-ACT intervention resulted in a 1-point improvement of restrained and uncontrolled eating.[18] Improvement of physical activity is defined as an increase of 700 MET-minutes per week during the intervention period. Rationale for this cut-off is 4.7 METs (physical activity at moderate intensity) * 150 minutes ≈ 700 MET-minutes per week.[23] Improvement of sedentary behavior is defined as a decrease of 1 sedentary hour per day during the intervention period based on previous studies.[24]

All statistical analyses were performed using SPSS version 27.

Ethical approval and informed consent

The study was conducted according to the guidelines of the Declaration of Helsinki, and approved on 9 March 2017 by the Ethics Committees of the participating hospitals (protocol code B322201730956). Informed consent was obtained from all subjects involved in the study.

Results

Participant characteristics

Figure 6.1 shows the participant flow. For the current analyses, 1075 participants were included: 524 control group participants and 551 intervention group participants. Underweight participants (n=16) and participants whose weight data were missing (n=48) were excluded from the current analyses. Baseline characteristics of participants are shown in Table 6.1.

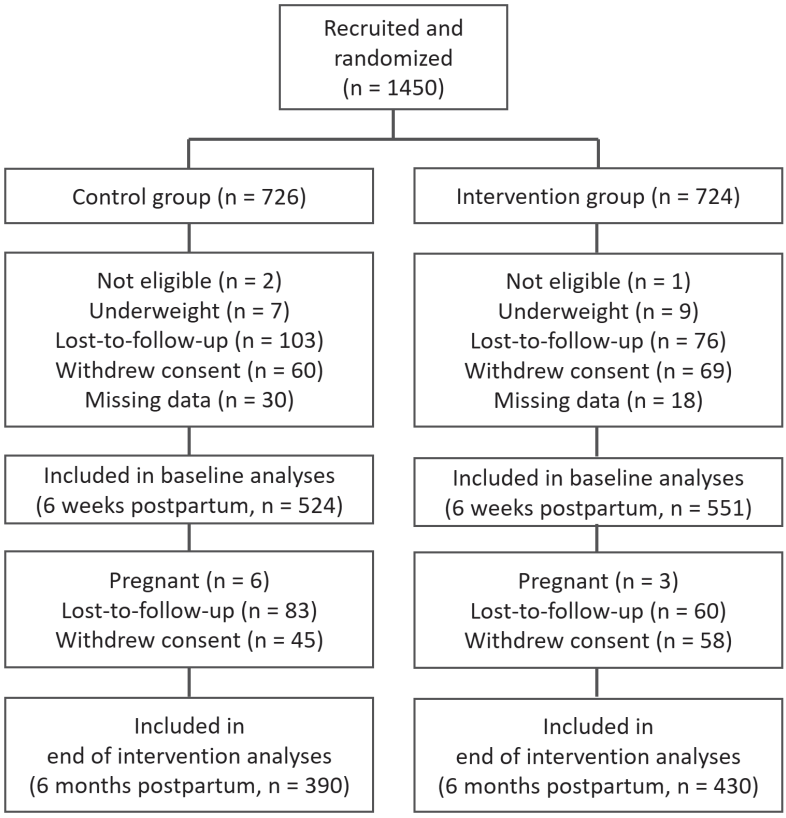

Figure 6.1. Flow chart of participant recruitment and follow-up.

Table 6.1. Participant characteristics.

	Control (n=524)	Intervention (n=551)
Age, mean (SD)	31.4 (3.9)	31.2 (4)
Highest education, n (%)		
Up to secondary education	149 (29.2)	155 (28.3)
College	199 (39)	212 (38.8)
University	162 (31.8)	180 (32.9)
Missing	14	4
Ethnicity, n (%)		
White European	462 (90.6)	486 (88.8)
Other ethnicity	48 (9.4)	61 (11.2)
Missing	14	4
Parity, n (%)		
Primiparous	295 (56.3)	293 (53.2)
Multiparous	229 (43.7)	258 (46.8)
Sex of infant, n (%)		
Boy	274 (52.3)	295 (53.5)
Girl	250 (47.7)	256 (46.5)
Pre-pregnancy BMI category, n (%)		
Normal weight	256 (48.9)	264 (47.9)
Overweight	187 (35.7)	196 (35.6)
Obesity	81 (15.5)	91 (16.5)
Gestational weight gain in kg, median (Q1-Q3)		
Among normal weight	19 (17-21)	18 (17-20)
Among overweight	16 (13-19)	16 (14-19)
Among obese	14 (12-17)	14 (11-17)

BMI = body mass index

Intervention effects on weight and body composition

No significant differences were found between intervention and control group regarding postpartum weight retention, fat percentage and waist circumference change from baseline (6 weeks postpartum) until the end of the postpartum intervention at 6 months postpartum (Table 6.2). Multivariate analyses adjusting for age, parity, and weeks between the two measurements did not result in different conclusions: there was no statistically significant evidence for differences between intervention and control group in weight retention, fat percentage and waist circumference (data not shown).

Table 6.2. Effects of the INTERACT intervention on postpartum weight and body composition

		BMI group	Control (n=524)	Intervention (n=551)	P
Weight retention in kg	Baseline (6 weeks PP)	Overall	6.8 (4.4)	6.9 (4.6)	
		NW	7.8 (4)	7.9 (4)	
		OW	6.2 (4.2)	6.6 (4.6)	
		OB	5.2 (5.1)	4.5 (5.1)	
	Change after intervention (6 months PP)	Overall	-2.4 (3.4)	-2.6 (4)	0.35
		NW	-3.1 (2.9)	-3.3 (3.2)	0.52
		OW	-1.8 (3.3)	-2.5 (3.9)	0.1
		OB	-0.9 (4.5)	-0.4 (5.5)	0.63
Fat %	Baseline (6 weeks PP)	Overall	35.1 (5)	35.3 (5.3)	
		NW	32 (3.9)	31.9 (4.4)	
		OW	36.7 (3.1)	37.2 (3.5)	
		OB	41.6 (3.4)	41.3 (3.3)	
	Change after intervention (6 months PP)	Overall	-1.5 (2.6)	-1.8 (2.8)	0.14
		NW	-2.2 (2.7)	-2.4 (2.8)	0.41
		OW	-1.1 (2.2)	-1.4 (2.7)	0.24
		OB	0 (2.7)	-0.5 (2.2)	0.26
Waist circumference in cm	Baseline (6 weeks PP)	Overall	87.9 (9)	89 (10)	
		NW	82.5 (5.5)	83.1 (6.9)	
		OW	89.7 (6)	90.9 (7.3)	
		OB	100.7 (8.8)	102 (9.1)	
	Change after intervention (6 months PP)	Overall	-3.9 (4.2)	-4 (4.9)	0.61
		NW	-4.7 (3.7)	-5 (4.3)	0.51
		OW	-3.1 (4)	-3.4 (5)	0.67
		OB	-2.4 (5.5)	-2.4 (6.3)	1

Values are mean (SD)

BMI = body mass index; NW = normal weight; OB = obesity; OW = overweight; PP = postpartum

Improvement of lifestyle behavior and relation to weight and body composition

Energy intake

Intervention group participants who reduced energy intake (i.e. decrease of ≥ 100 kcal/day) at the end of the intervention period, had lost a mean weight of 3.1 kg (SD 4.2) between 6 weeks and 6 months postpartum. Participants who did not reduce their energy intake had lost significantly less weight (mean 2.2 kg, SD 3.8, P=0.05)(Table 6.3). Likewise, women who reduced their energy intake had a larger decrease in fat percentage (mean 2.3%, SD 2.9 versus mean 1.4%, SD 2.7, P=0.01) and waist circumference (mean 4.6 cm, SD 4.8 versus mean 3.3 cm, SD 4.7, P=0.01) compared to those who did not reduce energy intake (Table 6.3). When stratified for pre-pregnancy BMI, the differences in weight, fat percentage and waist circumference were significant within the subgroup of participants who had overweight. In addition, the difference in waist circumference was also significant within the obesity subgroup (Table 6.3).

Restrained eating

A mean decrease in fat percentage of 2.2% (SD 3) between 6 weeks and 6 months postpartum was observed among intervention group participants who had improved restrained eating behavior (i.e. an increase of ≥ 1 point) by the end of the intervention. This was a significantly larger fat percentage decrease compared to women who had not improved their restrained eating score: their fat percentage decreased by 1.4% (SD 2.6)(P=0.02)(Table 6.3). Women who improved restrained eating behavior also had a larger reduction in waist circumference compared to those who did not improve: mean 4.5 cm (SD 4.8) versus mean 3.4 cm (SD 4.8), respectively (P=0.05). Within the subgroup of women with overweight, the difference in waist circumference reduction was even larger: mean 4.2 cm (SD 5.6) for those who improved restrained eating, and mean 1.8 cm (SD 4) for those who did not improve (P=0.01) (Table 6.3).

Overall, improved restrained eating was not associated with weight change. However, within the subgroup of women with overweight, a significantly larger postpartum weight loss was observed among those who improved restrained eating (mean 3.2 kg, SD 4.2) compared to those who did not (mean 1.4 kg, SD 3.5, P=0.01) (Table 6.3).

Uncontrolled eating

Intervention group participants who had improved on uncontrolled eating behavior (i.e. an increase of ≥ 1 point) at the end of the intervention, had significantly larger postpartum weight loss (mean 3.5 kg, SD 4.2) between 6 weeks and 6 months postpartum compared to participants who had not improved (mean 1.9 kg, SD 3.7, P<0.001). When the group was stratified for pre-pregnancy BMI, similar differences were found among women with normal weight and women with obesity, but not among women with overweight (Table 6.3).

We also observed a difference in decrease of fat percentage between 6 weeks and 6 months postpartum between those women who had improved uncontrolled eating (mean 2.3%, SD 2.9) and those who had not improved (mean 1.5%, SD 2.7, P=0.01). Again, the difference was also significant for women with normal weight and obesity, but not for women with overweight (Table 6.3).

Waist circumference had decreased significantly more in women who had improved uncontrolled eating (mean 2.3 cm, SD 2.9) compared to women who had not improved (1.5 cm, SD 2.7, P=0.01). Upon stratification into separate BMI-groups, the difference was only significant among women with obesity (Table 6.3).

Emotional eating

Improving emotional eating score (i.e. an increase of ≥ 1 point) was not associated with changes in weight, fat percentage, or waist circumference between 6 weeks and 6 months postpartum (Table 6.3).

Physical activity and sedentary behavior

Within the BMI-subgroup of women with pre-pregnancy obesity, women who improved physical activity (i.e. an increase of ≥ 700 METs per week) had a mean weight loss of 2.1 kg (SD 6.4) between 6 weeks and 6 months postpartum, whereas women who did not improve physical activity gained weight: mean 1.7 kg (SD 4.3, P=0.05) (Table 6.4). In the overall group and the other BMI sub-groups, improving physical activity was not associated with weight, fat percentage, or waist circumference change between 6 weeks and 6 months postpartum. Neither was improvement of sedentary behavior (i.e. a decrease of ≥ 1 sedentary hour per day) associated with change in weight, fat percentage, or waist circumference between 6 weeks and 6 months postpartum (Table 6.4).

Table 6.3. Difference between participants who improved nutrition-related lifestyle behavior and those who did not improve from 6 weeks until 6 months postpartum (intervention group only, n=357).

	Outcome	BMI group	Not improved*	Improved*	P
			Mean (SD)	Mean (SD)	
Energy intake			(n=150)	(n=207)	
	Weight loss in kg	Overall	-2.2 (3.8)	-3.1 (4.2)	0.05
		NW	-3.3 (3.4)	-3.3 (3.1)	0.91
		OW	-1.7 (3.9)	-3.3 (4.1)	0.02
		OB	+0.1 (3.5)	-1.4 (7)	0.38
	Fat % decrease	Overall	-1.4 (2.7)	-2.3 (2.9)	0.01
		NW	-2.4 (2.8)	-2.6 (2.9)	0.59
		OW	-0.4 (2.4)	-2.2 (2.7)	0.001
		OB	-0.3 (1.5)	-0.7 (2.9)	0.58
	Waist circumference decrease in cm	Overall	-3.3 (4.7)	-4.6 (4.8)	0.01
		NW	-5.7 (5.9)	-4.9 (3.9)	0.95
		OW	-2.1 (5)	-4.2 (5.2)	0.02
		OB	-1 (4.6)	-5 (6.6)	0.02
Restrained eating			(n=130)	(n=223)	
	Weight loss in kg	Overall	-2.2 (4)	-3 (4)	0.06
		NW	-3.4 (3.6)	-3.3 (3)	0.73
		OW	-1.4 (3.5)	-3.2 (4.2)	0.01
		OB	-0.2 (4.7)	-1.3 (6.4)	0.51
	Fat % decrease	Overall	-1.4 (2.6)	-2.2 (3)	0.02
		NW	-2 (2.7)	-2.8 (3)	0.1
		OW	-1.2 (2.5)	-1.8 (2.9)	0.26
		OB	0.2 (1.6)	-1 (2.6)	0.13
	Waist circumference decrease in cm	Overall	-3.4 (4.8)	-4.5 (4.8)	0.05
		NW	-4.8 (4.3)	-4.9 (3.7)	0.88
		OW	-1.8 (4)	-4.2 (5.6)	0.01
		OB	-2.8 (6.7)	-3.6 (5.6)	0.66

	Outcome	BMI group	Not improved*	Improved*	P
			Mean (SD)	Mean (SD)	
Uncontrolled eating			(n=170)	(n=183)	
	Weight loss in kg	Overall	-1.9 (3.7)	-3.5 (4.2)	<0.001
		NW	-2.8 (3)	-3.8 (3.4)	0.04
		OW	-2 (3.9)	-3.1 (4.2)	0.13
		OB	+0.6 (4)	-3.2 (7.4)	0.03
	Fat % decrease	Overall	-1.5 (2.7)	-2.3 (2.9)	0.01
		NW	-1.9 (2.8)	-3.1 (2.9)	0.009
		OW	-1.7 (3)	-1.4 (2.6)	0.65
		OB	+0.1 (1.4)	-1.8 (3.3)	0.02
	Waist circumference decrease in cm	Overall	-3.3 (4.8)	-4.7 (4.8)	0.006
		NW	-4.3 (3.9)	-5.3 (4)	0.1
		OW	-3 (5.3)	-3.6 (5.1)	0.52
		OB	-1.5 (5.2)	-6.3 (6.6)	0.008
Emotional eating			(n=229)	(n=124)	
	Weight loss in kg	Overall	-2.6 (4)	-3 (4.1)	0.33
		NW	-3.3 (3.2)	-3.4 (3.3)	0.95
		OW	-2.5 (4.2)	-2.8 (3.8)	0.73
		OB	+0.3 (4.8)	-2.5 (6.6)	0.1
	Fat % decrease	Overall	-1.8 (2.9)	-2.2 (2.7)	0.2
		NW	-2.5 (2.9)	-2.6 (2.8)	0.79
		OW	-1.3 (2.9)	-2 (2.5)	0.22
		OB	+0.1 (1.5)	-1.4 (3.1)	0.07
	Waist circumference decrease in cm	Overall	-4 (4.9)	-4.2 (4.7)	0.73
		NW	-5 (4.3)	-4.5 (3.3)	0.44
		OW	-3.1 (5.3)	-3.7 (5)	0.53
		OB	-2.5 (5.3)	-4.5 (7.2)	0.28

* Improvement of energy intake is defined as a 100 kcal decrease per day during the intervention period; improvement of restrained eating is defined as a 1-point increase during the intervention period; improvement of uncontrolled and emotional eating is defined as a 1-point decrease during the intervention period.

BMI = body mass index; NW = normal weight; OB = obesity; OW = overweight

Table 6.4. Difference between participants who improved physical activity and those who did not improve from 6 weeks until 6 months postpartum (intervention group only, n=315).

	Outcome	BMI group	Not improved* Mean (SD)	Improved* Mean (SD)	P
Physical activity			(n=148)	(n=167)	
	Weight in kg	Overall	-2.5 (3.9)	-2.9 (4.3)	0.42
		NW	-3.6 (3.5)	-3.1 (3.3)	0.43
		OW	-2.5 (3.6)	-2.9 (4.7)	0.67
		OB	+1.7 (4.3)	-2.1 (6.4)	0.05
	Fat %	Overall	-1.7 (2.7)	-2.1 (2.9)	0.25
		NW	-2.2 (2.7)	-2.5 (3)	0.6
		OW	-1.4 (2.7)	-2 (2.8)	0.26
		OB	-0.5 (1.6)	-0.6 (2.9)	0.98
	Waist in cm	Overall	-3.8 (4.4)	-4.3 (5.2)	0.41
		NW	-5.2 (4)	-4.5 (3.8)	0.23
		OW	-3 (4)	-3.7 (6.5)	0.53
		OB	-1.5 (5.5)	-5 (6.8)	0.1
Sedentary behavior			(n=177)	(n=138)	
	Weight in kg	Overall	-2.8 (4.5)	-2.6 (3.7)	0.55
		NW	-3.2 (3.6)	-3.4 (3.1)	0.78
		OW	-3.2 (4.3)	-2.0 (3.9)	0.12
		OB	0 (6.9)	-1.1 (4.4)	0.62
	Fat %	Overall	-1.8 (2.8)	-2.0 (2.8)	0.59
		NW	-2.2 (2.9)	-2.7 (2.8)	0.38
		OW	-1.7 (2.6)	-1.6 (2.9)	0.96
		OB	-0.5 (3)	-0.6 (1.3)	0.86
	Waist in cm	Overall	-4.1 (4.5)	-4.0 (5.2)	0.94
		NW	-4.9 (3.9)	-4.6 (3.8)	0.56
		OW	-3.1 (4.4)	-3.5 (6)	0.69
		OB	-3.4 (6.1)	-3.8 (7)	0.85

* Improvement of physical activity is defined as an increase of 700 METs per week during the intervention period; improvement of sedentary behavior is defined as a decrease of 1 sedentary hour per day during the intervention period.

BMI = body mass index; NW = normal weight; OB = obesity; OW = overweight

Discussion

The INTER-ACT RCT is unique in its approach of intervening between two pregnancies and during the subsequent pregnancy to prevent pregnancy-related complications. Reducing PPWR is a crucial first step in the prevention of future pregnancy related complications and intergenerational obesity. Especially women with preceding excessive GWG are at increased risk of PPWR and the related consequences. They are therefore targeted in the INTER-ACT RCT.

The current analyses examined the effects of the postpartum phase of the INTER-ACT intervention on PPWR and body composition. No statistically significant differences were found between intervention and control group regarding weight and body composition at the end of the postpartum intervention phase. However, at the end of the intervention, significantly larger decreases in weight, fat percentage and waist circumference were observed among participants who managed to reduce their energy intake, enhance restrained eating and decrease uncontrolled eating, compared to those who did not report these lifestyle improvements. These differences were generally reflected in the overweight and obesity BMI-subgroups. Improving emotional eating, physical activity and sedentary behavior were not related to changes in weight and body composition at the end of the intervention. Obese women who increased physical activity formed an exception to this: they had significantly larger weight reduction during the intervention period compared to those who did not increase physical activity.

Recent postpartum lifestyle interventions showed inconsistent findings regarding their effectiveness in reducing postpartum weight retention. In line with our findings, the lifestyle intervention 'Estudio Parto' (Project Aiming to Reduce Type twO diabetes) was not able to reduce postpartum weight.[25] The study population differed from the INTER-ACT study: Estudio Parto targeted Hispanic women with abnormal glucose tolerance during pregnancy. Over half of the Estudio Parto study population (56.9%) had preceding excessive GWG, whereas all INTER-ACT study participants had preceding excessive GWG by eligibility criteria. However, Estudio Parto had a very similar set-up to the INTER-ACT intervention, consisting of four face-to-face tailored sessions between 6 weeks and 6 months postpartum. In addition to these sessions, Estudio Parto also comprised 13 telephone booster sessions, whereas our intervention utilized a smartphone application to support participants in between the face-to-face sessions.[25] It can, however, not be concluded that the lack of effect regarding postpartum weight is due to the intervention set-up, as other interventions with an entirely

different set-up failed to reduce postpartum weight as well. For example, the HELP (Healthy Eating and Lifestyle in Pregnancy) weight management intervention among women with a BMI ≥30 kg/m^2 (33% had excessive GWG) did not result in lower postpartum weight compared to controls either.[26] The set-up of the HELP intervention was, however, distinctly different from the INTER-ACT intervention: it comprised weekly sessions that started during pregnancy and continued until 6 weeks postpartum.[26]

In contrast, the LIFE-Moms (Lifestyle Interventions for Expectant Moms) trials, targeting women with a BMI ≥25 kg/m^2, were effective in reducing postpartum weight retention.[27] LIFE-Moms consisted of seven different interventions that had in common that they all commenced during pregnancy. Apart from that, the interventions were heterogeneous in terms of number and timing of sessions and content (e.g. meal replacements, specific diets, or use of m-health).[27] It can therefore not be deducted which intervention aspects might have contributed to the observed weight loss. However, as these interventions commenced in pregnancy and lasted until postpartum, they ran for a longer time span, which might have been necessary to achieve improved lifestyle and subsequent weight reduction. Besides, the interventions might already have effectively limited GWG, which would be the first step towards less PPWR.

The lack of effect on PPWR and body composition might partly be explained by the relatively short intervention. However, there might potentially be a positive long-term effect of the intervention on health-related outcomes, especially because the intervention resumes in a subsequent pregnancy. Furthermore, other priorities that prevail in a mother's life during the postpartum phase might have affected intervention uptake. Time constraints, fatigue, and practical constraints because of the baby are, amongst other factors, mentioned as determinants of changes in eating behavior in the first year postpartum.[28]

No previous studies were found that specifically targeted postpartum women with preceding excessive GWG. This high-risk group needs special attention in order to prevent long-term adverse outcomes, and was therefore targeted in the INTER-ACT study.[7-9] Achieving postpartum weight loss is probably harder in this at-risk population compared to populations without excessive GWG. This might have played a role in the lack of effectiveness on postpartum weight and body composition on the short term as reported in the current analyses. Besides, due to the focus on women with excessive GWG in this study, the results cannot be generalized to the overall population of postpartum women.

In the current study, we found that improvements in energy intake, restrained eating and uncontrolled eating were associated with postpartum weight loss. Enhancing physical activity was only associated with more weight loss among women with obesity. Findings from Estudio Parto suggested that only increased physical activity and not healthy eating was associated with larger weight loss.[25] It is unclear what could explain this difference in findings between the INTER-ACT study and Estudio Parto. However, the findings of these two studies together do emphasize that lifestyle improvements probably lie at the basis of weight change. Behavior change therefore remains an important target to achieve reduction of postpartum weight retention.

Previously reported findings from the INTER-ACT study showed that the intervention effectively improved energy intake, restrained eating and uncontrolled eating.[18] The lack of reduction of PPWR as found in the current analyses, might imply that a larger improvement of lifestyle behavior is needed to achieve significant postpartum weight loss.

Upon stratification for the pre-pregnancy BMI-groups, almost all associations between lifestyle improvement and weight loss and body composition change that were found to be statistically significant in the overall group, were also observed within the overweight and obesity subgroups, but rarely in the normal weight subgroup. Moreover, improvement of physical activity was not associated with weight loss in the overall group, but was associated with weight loss among women with pre-pregnancy obesity. These findings suggest that behavior change might especially be beneficial among women with a pre-pregnancy BMI in the overweight or obese range. These women would therefore be an important target group in future lifestyle intervention studies.

In previous analyses that specifically focused on the INTER-ACT control group, it was pointed out that sedentary time, emotional eating and uncontrolled eating were lifestyle behaviors that played an important role in the spontaneous evolution of weight and body composition in the first year postpartum. In the current analyses, we found that within the intervention group, energy intake, restrained eating, uncontrolled eating and physical activity played a role in weight and body composition change. These findings together highlight the importance of incorporating a wide range of lifestyle behaviors into interventions.

To enhance feasibility of future implementation, the four INTER-ACT coaching sessions coincided with the existing postnatal care path and infant follow-up: sessions were scheduled at 6 weeks, 8 weeks, 12 weeks, and 6 months

postpartum. However, a limitation of this approach is that results measured at 6 months postpartum did not capture effects obtained during this fourth session. Another limitation is that the extensive measurements that were carried out in this study, might have had an intervention effect in the control group, as women might have been motivated to work on improving weight and body composition for the next measurement.

Conclusion

The INTER-ACT lifestyle intervention program targeting women with preceding excessive GWG was not effective in the reduction of PPWR and improvement of body composition measures. Improving energy intake, restrained eating and uncontrolled eating behavior were associated with higher postpartum weight loss and larger decrease of fat percentage and waist circumference. This emphasizes the need to incorporate not only nutritional intake but also eating behavior-related aspects in lifestyle interventions. Future analyses will investigate whether the INTER-ACT RCT was effective in reducing complications in a subsequent pregnancy.

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CHAPTER 7.

General discussion

Pre-pregnancy overweight or obesity, excessive gestational weight gain (GWG) and postpartum weight retention (PPWR) are related to short-term and long-term health consequences for both mother and child [1-3]. Lifestyle interventions during pregnancy reduce GWG, but do not substantially reduce complications [4]. The potential of lifestyle intervention in the postpartum phase is twofold. Firstly, postpartum intervention may reduce PPWR. Secondly, the postpartum phase is concurrently the pre-pregnancy phase of a next pregnancy (i.e., inter-pregnancy time window) and can therefore be utilized to prepare for a healthy future pregnancy.

Especially women with a history of excessive GWG would benefit from lifestyle intervention, as they are at increased risk of PPWR and consequently adverse health outcomes [4-6]. The INTER-ACT study targeted women with a history of excessive GWG by an intervention that combines face-to-face coaching with a smartphone application. The postpartum phase of the intervention commenced 6 weeks post-delivery and continues until 6 months post-delivery. A follow-up measurement was performed at 12 months post-delivery. Participants were then further followed up every 6 months until a subsequent pregnancy, in which the intervention resumed. However, the latter is not subject of my thesis. In the current thesis, we investigated lifestyle behaviors, weight and body composition up to one year postpartum as well as the effects of the postpartum lifestyle intervention on these factors. Eating behavior, energy intake, physical activity and sedentary behavior are important modifiable lifestyle behaviors that are likely to play a role in postpartum weight and health outcomes [7, 8]. These lifestyle behaviors, together with postpartum weight and body composition are therefore subject of this thesis. Figure 7.1 displays a summary of the findings from the analyses that we performed with the data from the INTER-ACT study. Below, we further elaborate on these findings.

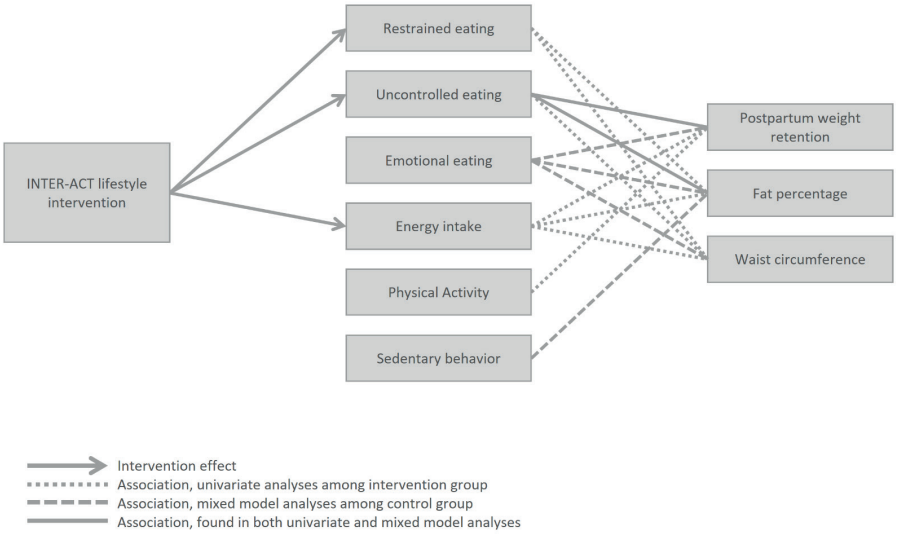

Figure 7.1. Overview of the findings from the INTER-ACT study data in the postpartum period.

Eating behaviors

The concept of eating behaviors encompasses patterns of internal and external circumstances under which individuals eat, food choices and motives, feeding practices, and dieting [9]. Eating behaviors may serve as driving factors of food intake and subsequently influence weight [10]. An overview of the associations between eating behaviors and perinatal weight changes (i.e., GWG and PPWR) was lacking. Therefore, we firstly systematically reviewed the scientific literature on this topic. Secondly, we studied associations between eating behaviors and postpartum weight and body composition in the INTER-ACT study population. Thirdly, we studied the impact of the INTER-ACT lifestyle intervention on eating behaviors. Below, we elaborate on these findings.

In our systematic review we describe that low levels of intuitive eating and high levels of restrained eating, external eating, emotional eating, food cravings and disinhibition are associated with higher GWG and excessive GWG [11]. Furthermore, high levels of restrained eating and intuitive eating are associated with less PPWR. Hence, supporting women in reinforcing intuitive eating and reducing external-, emotional-, and disinhibited eating and food cravings is potentially a key element in limiting excessive GWG and PPWR and should be integrated in future lifestyle interventions. It is less certain whether reinforcing restrained eating is desirable, as restrained

eating is related to higher weight in pregnancy, but lower weight in postpartum. The underlying mechanisms of these associations should be further explored.

The systematic review included studies published up to March 2020. After that date, more studies were published that provided insight into the topic of eating behaviors in relation to gestational and postpartum weight. A Chinese study by Zhang and colleagues conducted during the COVID-19 pandemic reported that a higher emotional eating score was associated with a higher risk of excessive GWG. This endorses the findings of our systematic review. Zhang et al. also reported an increased intake of high energy dense foods and therefore hypothesized that the association between emotional eating and excessive GWG is mediated by the craving for high energy dense foods [12]. Such mediation was already investigated and confirmed by Blau and colleagues in 2018 [13]. In contrast to the findings by Zhang et al. and previous findings of our systematic review, Shakeri and colleagues found in their study population of Iranian healthy pregnant women in (n = 360) that emotional eating predicted more inadequate GWG (i.e., GWG below the recommendation) [14]. Although emotions are generally linked to overeating, emotions might also result in food restriction [15, 16], which could explain a lower weight. However, Shakeri et al. assessed emotional eating by the Dutch Eating Behavior Questionnaire (DEBQ), which queries patterns of overeating following emotions rather than food restriction [17]. An explanation for the link between emotional eating and inadequate GWG as found by Shakeri et al. therefore remains unclear. Another recent study is published by Yu and colleagues. They reported that higher frequency of experiencing food cravings predicted higher GWG and higher risk of excessive GWG [18], which, again, supports the findings of our systematic review. The body of literature that highlights the associations between eating behaviors and GWG thus continues to grow. Moreover, there are also recent publications that investigated eating behaviors in relation to postpartum weight. Lee and colleagues found that intuitive eating contributed to a lower BMI among women between 6 months and 4 year postpartum [19]. This corresponds with previous findings of our systematic review. In addition, our analyses of the INTER-ACT study added to the literature on eating behavior and PPWR. These findings are discussed below.

We examined the role of eating behaviors in the spontaneous evolution of postpartum weight and body composition using linear mixed model analyses. This method enabled us to estimate how much the eating behavior scores at 6 weeks postpartum contributed to 1) PPWR and body composition at 6 weeks postpartum, and 2) the evolution of PPWR and body composition

between the time points (6 weeks, 6 months, 12 months postpartum). In addition, we estimated how much a change in eating behaviors from 6 weeks until 6 months postpartum contributed to 1) PPWR and body composition at 6 months postpartum, and 2) the evolution of PPWR and body composition between 6 months and 12 months postpartum. We found that emotional and uncontrolled eating played a role in the spontaneous evolution of postpartum weight and body composition. Emotional eating score was associated with a higher fat percentage and larger waist circumference at 6 weeks postpartum. Furthermore, if the emotional eating score increased between 6 weeks and 6 months postpartum, PPWR also increased from 6 months until 12 months. Among women with pre-pregnancy overweight, increasing uncontrolled eating score between 6 weeks and 6 months postpartum was associated with higher postpartum weight and higher fat percentage from 6 months until 12 months [20]. These findings, analyzed using linear mixed models, are an important step beyond cross-sectional associations. The findings demonstrate that eating behavior at 6 weeks and 6 months postpartum can be of predictive value to the evolution of PPWR and body composition on the longer term. This implies that interventions that successfully improve eating behaviors in early postpartum up to 6 months postpartum, can have long-lasting beneficial effects on PPWR and body composition.

In addition, using univariate analyses we found that decreasing uncontrolled eating score was associated with positive changes in body composition (i.e., fat percentage and waist circumference) as well as postpartum weight. Besides, increasing restrained eating score was also associated with beneficial postpartum body composition outcomes but not weight (Chapter 6). Thus, whereas previous literature only described associations between PPWR and restrained eating and intuitive eating, the INTER-ACT study added that emotional eating and uncontrolled eating are also important behavioral factors in relation to PPWR. In addition, no previous studies investigated the associations between eating behaviors and postpartum body composition, but our findings showed that eating behaviors are related to postpartum body composition as well. These findings underline the importance of tackling unhealthy eating behaviors and improving them by means of lifestyle interventions. Especially high-risk groups such as women with pre-pregnancy overweight or obesity, excessive GWG or PPWR should be targeted in such interventions, as they are at increased risk of adverse health outcomes. As not only weight but also body composition is an important determinant of health outcomes, future studies should also incorporate body composition measurements in order to measure their effects beyond weight.
The INTER-ACT intervention was effective in improving eating behaviors

in postpartum [21]. At 6 months postpartum, the restrained eating score of the intervention group was higher and the uncontrolled eating score of the intervention group was lower compared to the control group. This is an important and relevant finding, as we described above that restrained and uncontrolled eating are related to weight and body composition. However, the improved eating behaviors did not persist at follow-up: the differences disappeared at 12 months postpartum. In the subgroup of women with pre-pregnancy overweight, the uncontrolled eating score was even higher at follow-up in the intervention group compared to the control group. Although this seems at first as a negative long-term intervention effect, it is actually a relapse to baseline values. Post-hoc analyses among this subgroup of women with overweight showed that baseline uncontrolled eating scores were already significantly higher in the intervention group compared to the control group. This is an unexpected finding as baseline values are usually similar between the groups due to the randomized trial design. At the end of the intervention (i.e., 6 months postpartum) the scores were similar between the groups, indicating that the score actually decreased in the intervention group. At follow-up (i.e., 12 months postpartum) the uncontrolled eating score of the intervention group had declined to baseline values. This was confirmed in post-hoc analyses (data not shown). Thus, the higher uncontrolled eating scores at follow-up among women with overweight do not indicate a negative long-term intervention effect, but rather a relapse to baseline values.

Similar to the INTER-ACT intervention, the USA Fit Moms intervention was also effective in increasing restrained eating score. This internet-based postpartum intervention commenced between 6 months and 12 months postpartum, and lasted for 12 months. The Fit Moms intervention targeted women with overweight or obesity, or with more than 4.5 kg PPWR. The target population thus differed from the population of the INTER-ACT study, although it is likely that part of the Fit Moms study population also had excessive GWG in the preceding pregnancy. It was observed in the Fit Moms intervention that restrained eating score had increased after the first 6 months of intervention; after the subsequent 6 months of intervention, the restrained eating score did not further increase, but remained stable [22]. This might imply that prolonged intervention prevents relapse of results after 6 months, but does not continue to improve healthy lifestyle habits after 6 months. No data were published on follow-up after the end of the Fit Moms intervention. It is therefore unknown whether the improved eating behaviors persisted on the long term, or whether achievements also disappeared after the intervention ended, alike in the INTER-ACT study. Whereas the INTER-ACT intervention resulted in a 1-point difference in restrained eating score

between the intervention and control group, the Fit Moms intervention resulted in a 1.9-point difference between groups. As the restrained eating score remained stable after 6 months intervention in the Fit Moms trial, it is unlikely that this larger difference compared to the INTER-ACT study can be attributed to the longer duration of the Fit Moms intervention. The larger difference in the Fit Moms intervention might rather imply that their intervention design was more effective than the INTER-ACT intervention. Alternatively, the larger difference might indicate that the participants were more ready for behavior change as the intervention commenced later in postpartum: between 6 and 12 months postpartum, compared to 6 weeks postpartum in the INTER-ACT intervention. Although starting an intervention as early as 6 weeks postpartum might entail a challenge for some women in combination with recovery from childbirth and care for the infant, we remain convinced that 6 weeks postpartum is an appropriate time for intervention: mothers are still on maternity leave, the appointments can coincide with the existing postnatal and well-child care appointments, and the life-changing event of giving birth presents a 'teachable moment', which is an opportune time for intervention [23].

Energy intake

An imbalance between energy intake and energy expenditure is widely recognized to be responsible for weight gain. Consequently, energy intake is an important factor for the reduction of PPWR [24]. However, in linear mixed model analyses we found no evidence that energy intake contributed to the spontaneous evolution of PPWR and body composition in the first year postpartum [20]. Yet, in univariate analyses, we described that participants who decreased their daily energy intake with at least 100 kcal by the end of the intervention, had a significantly larger decrease in weight, fat percentage and waist circumference compared to participants who did not decrease their daily energy intake by at least 100 kcal (Chapter 6). These results appear ambiguous, but this can be attributed to the different methods of analyses applied. The former analyses were linear mixed models aiming to describe the role that lifestyle behaviors including energy intake play in the spontaneous evolution of PPWR and body composition. The latter were univariate analyses aiming to examine whether improving lifestyle between 6 weeks and 6 months postpartum, including energy intake, was associated with better PPWR and body composition. Energy intake thus remains an important target in postpartum weight management efforts.

Moreover, the INTER-ACT intervention effectively reduced daily energy intake by 69 kcal [21]. Although statistically significant, this is only a small difference and clinical relevance of this difference is uncertain. For example, it is assumed that a decrease of 7700 kcal is needed for one kilogram of weight loss, which can be achieved by decrease of energy intake or increase of energy expenditure by physical activity [25]. With a difference of 69 kcal between intervention and control group, it is unlikely that this results in a robust difference in weight. Indeed, the intervention globally did not result in better weight outcomes in the intervention group compared to the control group, as will be further elaborated on below (Chapter 6). Among the subgroup of women with pre-pregnancy obesity, the intervention had a stronger effect than in the overall group: a reduction of 174 kcal in the intervention group compared to the control group. This is an important finding, as it indicates that the intervention is most effective among women at highest risk (i.e., women with obesity) of adverse health outcomes. Nonetheless, the reduction of 174 kcal did neither result in lower weight or better body composition outcomes among the subgroup of women with obesity.

However, it is likely that the differences between intervention and control group (i.e., 69 kcal and 174 kcal) are actually an underestimation of the real difference. The daily caloric intake was calculated by use of a food frequency questionnaire (FFQ). The mean energy intake as calculated from this FFQ was in the control group at baseline, end of the intervention, and follow-up respectively 1399 kcal, 1277 kcal, and 1174 kcal. In the intervention group, this was respectively 1409 kcal, 1204 kcal, and 1172 kcal. This is considerably lower than the average reference intake of 2000 kcal per day for women [26]. A lower energy intake than the recommendation can potentially be explained by participants' efforts for caloric restriction. Yet, mean energy intake values deviate remarkably from the reference intake, which is more likely due to underreporting, especially since similar values are observed in intervention and control group and across all time points. If the actual mean energy intake is supposedly higher, the actual difference between intervention and control group is potentially also larger than 69 kcal and 174 kcal. The intervention effect on energy intake might thus actually be larger than measured.

Physical activity and sedentary behavior

Postpartum physical activity can contribute to postpartum recovery, prevention of depressive symptoms, and cardiovascular fitness [27, 28]. In addition, obese women who are moderately or highly physically active are more likely to lose all pregnancy weight by 6 months postpartum [29]. However, women are often less physically active in the postpartum period than before [27]. Postpartum physical activity should therefore be promoted [27].

Among women with obesity, we found that increased physical activity levels at the end of the intervention were associated with decreased postpartum weight (Chapter 6). This finding emphasizes the importance of enhancing physical activity among postpartum mothers with obesity. Yet, the INTER-ACT intervention did not have an impact on physical activity in any of the BMI groups [21].

Sedentary behavior is a relatively new element of focus in lifestyle interventions compared to physical activity. However, the importance of reducing sedentary behavior for optimal health is already widely recognized. Even individuals who are physically active can simultaneously spend a lot of time in seated or lying position, resulting in an increased risk of metabolic disorders [8, 30, 31]. It is furthermore suggested that sedentary behavior, eating behavior and food intake are intertwined. For example, demanding cognitive work, which might increase stress levels, is often done in seated position. The elevated stress levels during this sedentary activity might result in food cravings and increased food intake [8].

In our study, we found that high sedentary time was associated with high fat percentage at six weeks postpartum [20]. Both increased fat mass and sedentary behavior are associated with adverse health outcomes such as cardiovascular disease [31, 32]. This finding therefore implies that encouraging a less sedentary lifestyle might eventually result in beneficial health effects. The World Health Organization recommends for the general population a reduction of sedentary behavior, although there is still insufficient evidence to formulate a threshold [30]. Studies on sedentary behavior specifically conducted in the postpartum period are lacking. No evidence was found for a reduction of sedentary time by the INTER-ACT intervention [21]. Although it is possible that the intervention in itself did indeed not impact sedentary behavior, this could also be due to a measurement error. We used the International Physical Activity Questionnaire (IPAQ) to estimate physical activity and sedentary time. Although this questionnaire is validated and regarded to be appropriate to assess physical activity [33], it might be less suitable to assess sedentary time. The sedentary behavior section of the questionnaire only comprises two questions, in which participants are asked to estimate their average time spent sitting on respectively weekdays and weekend days. It might be difficult for participants to do this estimation. It is previously suggested that a more detailed measure is required to gain good insight into sedentary behavior patterns [34]. A more objective method for the measurement of sedentary behavior is the use of accelerometers [35].

Phase angle

Bio-electrical impedance analysis (BIA) is a method to determine body composition components. An electrical current is sent through the body and the BIA device measures resistance (caused by extracellular body water) and reactance (the delay caused by entering the cell walls). A number of parameters can be derived from the resistance and reactance, among which phase angle [36]. Phase angle reflects cell function, with higher values representing better cell function. It is used for the prognosis of certain diseases and is besides an indicator for nutritional status and fitness [36-40]. Age, gender and BMI also influence phase angle values [41]. Only few studies reported phase angle values in postpartum, and these were conducted among small study populations or predominantly underweight women [42-45]. We explored phase angle values among control group participants of the INTER-ACT study, providing novel information on phase angle values among women with a history of excessive GWG. We found that phase angle values slightly increased between 6 weeks and 12 months postpartum, which might imply that health status improved over this time period [46]. The clinical relevance of measuring phase angle values in postpartum remains uncertain. Future research should explore whether phase angle in the postpartum period can be used as a predictor for long-term maternal health outcomes.

Intervention effects on weight and body composition

Lifestyle behaviors including eating behaviors, energy intake, physical activity and sedentary behavior are suggested to contribute to weight changes in general populations as well as in postpartum women [47, 48]. As described above, our findings underline the associations between lifestyle behaviors and weight as well as body composition in mothers who had excessive GWG during the preceding pregnancy.

We hypothesized that the INTER-ACT lifestyle intervention would improve postpartum eating behaviors, decrease energy intake, increase physical activity, decrease sedentary time, decrease PPWR and improve body composition. Although the INTER-ACT lifestyle intervention effectively improved part of the lifestyle behaviors, the intervention did not impact weight and body composition at 6 months postpartum (Chapter 6). Also, the intervention effects on lifestyle behaviors were smaller than expected. This could be explained by the demanding postpartum period, the 'intervention-effect' in the control group, the ambitious goal of the intervention and/or the untimely measurement of outcomes. This is further outlined below.

Firstly, the early postpartum is a demanding time for most mothers. Time and energy constraints might have impaired substantial behavior change and weight loss efforts [48, 49]. To overcome this barrier, the timing of the sessions of the INTER-ACT intervention coincided with the appointments in the standard postnatal care path and routine well-child appointments. Following implementation of the intervention, this would facilitate participation in the program [50]. However, during the trial, it was not feasible to actually make intervention appointments coincide with the existing care path as the trial was not provided by the health care professionals that execute postnatal care. However, the INTER-ACT lifestyle coaches were highly flexible regarding day, time and place when and where the sessions took place in order to reduce these barriers as much as possible. An additional strategy to overcome the barrier of time constraints was the incorporation of a smartphone application into the intervention trial. This supported participants in their behavior change at any convenient time and place [48].

Secondly, extensive body measurements were conducted in the intervention group as well as the control group. The advantage is that this has aided us to investigate not only weight but also body composition measurements. A potential disadvantage is, however, that this might have unintendedly led to an 'intervention-effect' in the control group. Being weighed and measured at multiple time points potentially motivated control group participants to make an effort for better outcomes at the next measurement appointment. The control group can in that respect not be perceived as a completely unbiased control group. Personal conversations with control group participants learned us that some were determined to show that they did not need the intervention to achieve weight loss and body composition improvement, which underlines the 'intervention-effect' of being a control group participant. It cannot be estimated how large the role of this 'intervention-effect' was in the control group participants. However, if this effect was systematically present among control group participants, it is plausible that this has resulted in an underestimation of the real effect of the intervention.

Thirdly, achieving weight loss through an intervention that targets healthy lifestyle behaviors in four sessions over a time span of approximately 20 weeks might be a too ambitious goal. The INTER-ACT intervention did result in moderately improved lifestyle habits, but these improved lifestyle habits should probably be persisted over a longer time span to result in weight loss and body composition improvement. Yet, it should be considered whether weight loss should be the only determinant that represents a successful lifestyle intervention. For example healthier lifestyle habits are also of

importance for better health outcomes, regardless of weight [51, 52]. A core outcome set for postpartum weight retention is needed, but does at present not exist [53]. A core outcome set (COS) is defined as "an agreed minimum set of outcomes that should be measured and reported in all clinical trials of a specific disease or trial population." [54] Such a core outcome set should comprise outcomes that are considered important by a wide range of stakeholders, including health professionals as well as postpartum women themselves [53]. Not only patient-related outcome measures (PROMS) but also patient-reported experience measures (PREMS) should be taken into account [55]. A COS for use in postpartum lifestyle interventions would enhance comparability of studies on outcomes, prevent selective reporting of positive outcomes (i.e., reporting bias), and ensure that outcomes are relevant to the stakeholders [56].

Fourthly, the timing of the outcome measurement might have been suboptimal. The outcomes of the postpartum phase of the intervention were measured at 6 months postpartum, which coincided for the intervention group participants with the last coaching session of the postpartum phase. As a consequence, the effects gained during this last coaching session are not reflected in the measurement. Future development of a core outcome set should ideally also incorporate an advise on the timing of the outcome measurements.

Several elements of effective intervention strategies are described in literature. Group interventions are potentially effective approaches for optimizing healthy lifestyle and weight loss. In different target populations, peer support is perceived as an important element of behavior change [48, 57, 58]. In the antenatal period, there are several peer support interventions that target breastfeeding initiation [59]. For women in the postpartum phase, group sessions might not be the best approach because of child-care responsibilities [48]. The INTER-ACT intervention was therefore flexible in its approach; intervention group participants could indicate their preference for either group or individual intervention sessions. Furthermore, partners should be involved in postpartum lifestyle interventions [60]. A focus group study pointed out that partners were eager to be involved and perceived themselves as crucial resource for lasting lifestyle changes [61]. Although in a subsample of the INTER-ACT study population partners were asked to fill out questionnaires (data not shown in this thesis), it was for this trial not attainable to involve all partners in the intervention. Other elements of effective strategies for postpartum weight loss include self-monitoring and a combination of healthy eating and physical activity. Both elements were incorporated in the INTER-ACT lifestyle intervention program.

The intervention comprised two major components: face-to-face coaching and use of a smartphone application. We hypothesize that the results of the intervention can be derived from the combination of the face-to-face coaching and smartphone application, but this hypothesis cannot be tested due to the design of the trial. To adequately test this hypothesis, a four-arm trial would be needed: respectively a face-to-face coaching group, a smartphone application group, a face-to-face coaching plus smartphone application group, and a standard care control group. However, a much larger sample size would be needed for such a four-arm trial design. Because it was not an aim of the trial to investigate which component of the trial was most effective, the choice for a two-arm trial (i.e., a coaching plus application intervention group and a standard care control group) was made. However, interim analyses of the INTER-ACT trial showed that intervention group participants with high usage of the smartphone application (upper 50% of app use occasions) had slightly better outcomes in terms of PPWR at start of the subsequent pregnancy, compared to those with low app-usage (respectively 3.62 kg and 5.22 kg PPWR, effect size 0.021, p = 0.03; data not shown in this thesis). However, this finding does not imply causation. It is possible that the participants with the highest intrinsic motivation and intervention engagement, including engagement in application use, were most successful regarding postpartum weight loss.

In addition to the lifestyle behaviors discussed in this thesis, mental well-being was an important focal point of the INTER-ACT intervention. Literature shows that depression, stress, and anxiety are related to excessive GWG and PPWR [62, 63]. Mental health is thus a very relevant and important topic of investigation in our study population of postpartum women with a history of excessive GWG. Associations between mental health and PPWR and body composition, as well as intervention effects on mental health are therefore subject of future analyses.

A potential source of bias of the results lies in the use of self-administered questionnaires. Both recall bias and social desirability bias might have influenced the results. Intervention effects and associations might therefore in reality be weaker or stronger than reported; it cannot be estimated in which direction the bias would have influenced the results. For the eating behavior questionnaire and food frequency questionnaire, no suitable alternative is available. Data obtained through the International Physical Activity Questionnaire for physical activity and sedentary behavior could have been complemented with the use of accelerometers. However, in the current trial the use of accelerometers was not feasible due to the large sample size.

The findings of this study cannot be fully generalized to the overall population. Indeed, we focused on a very specific target population: women with excessive GWG in the preceding pregnancy. However, this target population covers approximately 40 to 50 percent of all pregnant women [64-66]. In addition, our study population was comparatively highly educated and little ethnically diverse.

Attrition and loss to follow up were major issues in our study. Between baseline (6 weeks postpartum) and end of the postpartum intervention (6 months postpartum), 25% of control group participants and 21% of intervention group participants had withdrawn from the study or were lost to follow-up. This is comparable to attrition rates in other studies [48]. The slightly higher attrition rate in the control group might be explained by dissatisfaction with not being randomized into the intervention group [48]. As no measurements were performed in between the 6 weeks' and 6 months' time points, it remains unclear whether attrition is related to (lack of) success in improving lifestyle and weight. Participants could have lost interest in the intervention if they reached their personal lifestyle and/or weight goals before the end of the intervention, or have given up due to the absence of expected results. Attrition due to (lack of) success might have biased study results and affected generalizability of the findings. Another potential reason for attrition is the extensive data collection that might have been burdensome to participants [48]. We attempted to make data collection attainable for participants, by sending out the questionnaires two weeks in advance of the measurement appointment by email, so that participants could fill questionnaires out at a place and time convenient to them. Probably this has reduced, but not removed the barrier of the extensive data collection.

Recommendations for future research

Following our findings from the postpartum phase of the INTER-ACT study, as described above, we would like to propose the following recommendations for future research:

1. Study causal pathways between eating behaviors, food intake, and weight and body composition;
2. Conduct further studies on effective strategies to reduce sedentary time in postpartum;
3. Investigate the predictive value of phase angle for long-term maternal health outcomes;
4. Involve the partners of postpartum women in future lifestyle interventions and evaluate whether this results in better outcomes;

5. Develop a core outcome set for postpartum weight retention that should be measured after postpartum lifestyle interventions, including optimal timing for the measurement of those outcomes;
6. Investigate how postpartum lifestyle intervention impacts mental well-being and whether this is related to postpartum weight retention and body composition among women with a history of excessive GWG;
7. Examine the effects of the postpartum lifestyle intervention on health outcomes in a subsequent pregnancy (gestational diabetes, pregnancy-induced hypertension, cesarean section, large for gestational age infant) and on long-term maternal health among women with a history of excessive GWG.

Implications for clinical practice

Obesity is a rapidly growing problem. The time around pregnancy poses a risk for increasing weight of women as well as an intergenerational cycle of obesity which affects the child. Simultaneously, the time around pregnancy provides an opportunity for lifestyle intervention. The postpartum period of a pregnancy can be perceived as the preconception period of a subsequent pregnancy, and is therefore an important time to intervene. The findings from the postpartum phase of the INTER-ACT study carry implications for clinical practice. Intervening between 6 weeks and 6 months postpartum through face-to-face coaching sessions and a smartphone application is promising for working towards a healthy lifestyle. Especially eating behaviors and energy intake are affected by this postpartum intervention. While healthy eating and physical activity are regularly the focal points of weight management efforts, eating behaviors are less often targeted. However, eating behaviors appear to be key elements in GWG, PPWR, and postpartum body composition, and should therefore be incorporated as focal points of weight management efforts in pregnancy and postpartum.

Conclusion

The primary aim of the INTER-ACT study was to reduce gestational diabetes, pregnancy-induced hypertension, caesarian sections, and large for gestational age in infants by intervening as early as the preceding inter-pregnancy phase. Women with excessive GWG in the preceding pregnancy were targeted, as they are a high-risk group for those complications. In the current thesis, we investigated the effects of the INTER-ACT intervention on postpartum lifestyle behaviors, weight and body composition. Optimal lifestyle and weight in postpartum are a crucial first step towards starting a next pregnancy healthily and reducing pregnancy- and birth- related

complications. We showed that the postpartum phase of the INTER-ACT lifestyle intervention had moderate but important effects on eating behaviors and energy intake among women with a history of excessive GWG. In addition, several associations between eating behavior, energy intake, physical activity, and sedentary behavior and postpartum weight and body composition were established. This knowledge can guide future lifestyle intervention efforts and contribute to healthier generations.

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7



Summary

Excess weight before, during and after pregnancy entails several maternal and infant adverse health outcomes. We elaborated on the state of the art of this topic in Chapter 1. Lifestyle factors such as food intake, physical activity and sedentary behavior are important contributors to maternal perinatal weight changes. In addition, eating behaviors such as restrained, uncontrolled, and emotional eating are potentially important determinants of perinatal weight change. We systematically reviewed the existing literature on the associations between eating behaviors and gestational weight gain and postpartum weight retention (Chapter 2). Several links between eating behaviors and perinatal weight were found. Intuitive eating is associated with lower gestational weight gain; restrained eating, external eating, emotional eating, food cravings and disinhibition are associated with higher gestational weight gain. Restrained eating and intuitive eating are in addition associated with less postpartum weight retention. However, we also identified studies that did not describe the aforementioned associations, indicating that evidence is not indisputable. Nevertheless, the direction of the reported associations was consistent across studies; no conflicting results were found. Research on eating behaviors in relation to postpartum weight is scarce, although the postpartum period emerges as a potentially important period to target eating behaviors for the reduction of postpartum weight retention.

We studied lifestyle behaviors (eating behavior, energy intake, physical activity, and sedentary behavior) in the postpartum period of women who showed excessive gestational weight gain in the preceding pregnancy. In Chapter 3 we examined the role of these lifestyle behaviors in the spontaneous evolution of weight, fat percentage, and waist circumference between 6 weeks and 12 months after delivery in a subsample of the INTER-ACT study population. At 6 weeks postpartum, the amount of sedentary time was associated with fat percentage; emotional eating score was associated with both fat percentage and waist circumference. An increasing emotional eating score between 6 weeks and 6 months postpartum was associated with an increase in weight between 6 months and 12 months postpartum. Within the subgroup of women with pre-pregnancy overweight, an increasing uncontrolled eating score between 6 weeks and 6 months postpartum was associated with higher weight and fat percentage between 6 months and 12 months postpartum. Thus, from these analyses, sedentary time, emotional eating, and uncontrolled eating appeared to be related to postpartum weight and body composition up to 1 year after delivery in women with preceding excessive gestational weight gain. Restrained eating, energy intake and physical activity were not found to play a role in the evolution of weight and body composition up to 1 year after delivery.

Phase angle is an indicator for nutritional status and fitness in several populations. It is measured using bio-electrical impedance analysis. It is a relatively novel measure that is understudied, especially among postpartum populations. In Chapter 4 we explored phase angle values during the first year after delivery in a subsample of the INTER-ACT study population. We found a small increase in phase angle values between 6 weeks and 12 months postpartum, which indicates an improving health status. The implication of these phase angle values on the longer term need to be further elucidated, for example whether phase angle in early postpartum is predictive of maternal health outcomes on the long term.

Various lifestyle intervention initiatives in pregnancy have previously attempted to limit pregnancy weight gain and risks of adverse outcomes. Despite moderate effects on weight, these interventions have insufficiently impacted complications. Preconception interventions are promising for the reduction of pregnancy complications, as they are probably more timely to achieve an optimal lifestyle and weight before pregnancy. The postpartum phase is simultaneously the preconception phase of a subsequent pregnancy and provides an opportunity to intervene among high-risk groups. The INTER-ACT randomized controlled trial (n = 1450) is a novel lifestyle intervention that is administered during the postpartum period and the subsequent pregnancy with the primary aim to reduce pregnancy-related complications. Specifically the high-risk group of women with excessive gestational weight gain in the preceding pregnancy is targeted in this study. This occurs in 40% to 50% of all pregnant women.

A healthy lifestyle is, regardless of weight, related to better health outcomes. In addition, improving lifestyle is a first step towards weight reduction. In Chapter 5 we evaluated whether the postpartum phase of the INTER-ACT lifestyle intervention had an impact on eating behaviors, energy intake, physical activity and sedentary behavior. At the end of the postpartum intervention (i.e., 6 months postpartum) the intervention group had a higher restrained eating score, lower uncontrolled eating score and lower energy intake compared to the control group. These differences did not persist at 6 months follow-up, except for the restrained eating score among women with a normal BMI, which remained higher in the intervention group than in the control group. In the subgroup of women with pre-pregnancy overweight, we found a higher uncontrolled eating score at follow-up in the intervention group compared to the control group, even though there was no difference at the end of the intervention. This unexpected finding can be attributed to a relapse to baseline values rather than a negative intervention effect. The lifestyle intervention did not affect emotional eating score,

physical activity levels and sedentary time in the overall intervention group, nor in any of the BMI subgroups. Subsequently we evaluated whether the postpartum phase of the INTER-ACT lifestyle intervention affected weight, fat percentage and waist circumference. In addition, we assessed whether improving lifestyle behaviors (i.e., decreasing energy intake, uncontrolled eating, emotional eating, or sedentary time; or increasing restrained eating, or physical activity) by the end of the intervention was associated with more weight loss or larger decrease of fat percentage or waist circumference during the intervention. In Chapter 6 we describe the effect of the lifestyle intervention on weight and body composition. We found no change in weight and body composition between 6 weeks and 6 months postpartum as a result of the lifestyle intervention. We did find that reducing energy intake and decreasing uncontrolled eating were both associated with more weight loss, larger decrease of fat percentage and larger decrease of waist circumference, compared to participants who did not improve these behaviors. In addition, increasing restrained eating was associated with larger decrease of fat percentage and waist circumference, but not with weight loss. Such associations were not found for improving emotional eating, physical activity and sedentary behavior.

The findings described in this thesis can guide future postpartum lifestyle intervention efforts. In Chapter 7 we formulated recommendations for practice as well as for future research. In addition to healthy eating and physical activity, eating behaviors should be targeted in future weight management efforts. However, causal pathways between eating behaviors, food intake, and weight and body composition needs further elucidation in future studies. Sedentary behavior is another understudied lifestyle behavior in postpartum. Effective strategies to reduce sedentary time in postpartum and effects on weight should be further investigated. A core outcome set for postpartum lifestyle interventions does currently not exist. Development and use of such a core outcome set would enhance comparability of studies and ensure that measured outcomes are relevant and important to the stakeholders. Lastly, the long-term effects of the postpartum lifestyle intervention, in terms of maternal health and weight as well as complications in a subsequent pregnancy, should be investigated.



Samenvatting

Overmatig gewicht voor, tijdens en na de zwangerschap brengt verschillende nadelige gevolgen voor de gezondheid met zich mee voor zowel moeder als kind. In Hoofstuk 1 hebben we de huidige stand van zaken van dit onderwerp uitgewerkt. Leefstijlfactoren zoals voedingsinname, fysieke activiteit en sedentair gedrag leveren een belangrijke bijdrage aan perinatale gewichtsveranderingen. Daarnaast is eetgedrag, zoals restrictief eten, ongecontroleerd eten en emotioneel eten, mogelijk een belangrijke determinant van perinatale gewichtsverandering. We voerden een systematische review uit van de bestaande literatuur omtrent associaties tussen eetgedrag en gewichtstoename tijdens de zwangerschap en postpartum gewichtsretentie (Hoofdstuk 2). Verschillende verbanden werden gevonden tussen eetgedrag en perinataal gewicht. Intuïtief eten is geassocieerd met lagere gewichtstoename tijdens de zwangerschap; restrictief eten, extern eten, emotioneel eten, cravings (een sterke drang naar eten), en ongeremd eten zijn geassocieerd met hogere gewichtstoename tijdens de zwangerschap. Restrictief en intuïtief eten zijn daarnaast geassocieerd met minder postpartum gewichtsretentie. We vonden echter ook onderzoeken die de voorgenoemde associaties niet vaststelden, wat er op duidt dat het bewijs niet onomstotelijk is. Desalniettemin was de richting van de gevonden verbanden consistent tussen de studies; er werden geen tegenstrijdige bevindingen gedaan. Onderzoek naar eetgedrag in relatie tot postpartum gewicht is schaars, hoewel de postpartum periode een mogelijk belangrijke periode is om te richten op eetgedrag voor de vermindering van postpartum gewichtsretentie.

We onderzochten leefstijlfactoren (eetgedrag, energie inname, fysieke activiteit, en sedentair gedrag) in het postpartum bij vrouwen die excessieve gewichtstoename hadden vertoond tijdens de voorgaande zwangerschap. In Hoofdstuk 3 onderzochten we de rol van deze leefstijlfactoren in het spontane verloop van gewicht, vetpercentage en middelomtrek tussen 6 weken en 12 maanden na de bevalling in een subgroep van de INTER-ACT studiepopulatie. Op 6 weken postpartum was sedentaire tijd geassocieerd met vetpercentage; emotioneel eten was geassocieerd met zowel vetpercentage als middelomtrek. Een toenemende mate van emotioneel eten tussen 6 weken en 6 maanden postpartum was geassocieerd met een toename van gewicht tussen 6 maanden en 12 maanden postpartum. Binnen de subgroep van vrouwen met overgewicht voorafgaand aan de zwangerschap was een toenemende mate van ongecontroleerd eten tussen 6 weken en 6 maanden postpartum geassocieerd met een hoger gewicht en vetpercentage tussen 6 maanden en 12 maanden postpartum. In deze analyses bleken sedentaire tijd, emotioneel eten en ongecontroleerd eten dus gerelateerd te zijn aan gewicht en lichaamssamenstelling tot 1 jaar na

de bevalling bij vrouwen die een excessieve gewichtstoename hadden in de voorafgaande zwangerschap. Restrictief eten, energie-inname en fysieke activiteit speelden in deze analyses geen rol in de evolutie van gewicht en lichaamssamenstelling tot 1 jaar na de bevalling.

Fasehoek is een indicator voor voedingsstatus en fitheid in verschillende populaties. Het wordt gemeten met behulp van bio-elektrische impedantie analyse. Het is een relatief nieuwe maat die vooral onder postpartum populaties nog weinig is bestudeerd. In Hoofdstuk 4 exploreerden wij fasehoekwaardes tijdens het eerste jaar na de bevalling in een subgroep van de INTER-ACT studiepopulatie. We vonden een kleine toename in fasehoekwaarden tussen 6 weken en 12 maanden postpartum, wat duidt op een verbeterende gezondheidsstatus. De betekenis van deze fasehoekwaarden op de langere termijn moet verder verduidelijkt worden, bijvoorbeeld of de fasehoek in het vroege postpartum een voorspeller is voor gezondheidsuitkomsten bij de moeder op de lange termijn.

Verscheidene leefstijlinterventies tijdens de zwangerschap hebben gepoogd om gewichtstoename tijdens de zwangerschap en het risico op complicaties te beperken. Ondanks redelijke effecten op gewicht, hebben deze interventies onvoldoende impact op complicaties. Preconceptie interventies zijn veelbelovend voor de vermindering van zwangerschapscomplicaties, omdat ze waarschijnlijk tijdig een optimale leefstijl en gewicht kunnen bereiken vóór de zwangerschap. De postpartum fase is tegelijkertijd de preconceptiefase van een volgende zwangerschap en vormt daarom een optimale gelegenheid om te interveniëren bij hoog-risicogroepen. De INTER-ACT studie, een gerandomiseerde gecontroleerde studie (n = 1450), is een vernieuwende leefstijlinterventie die werd toegepast tijdens de postpartum periode en de volgende zwangerschap met het primaire doel om zwangerschap gerelateerde complicaties terug te dringen. We richtten ons in deze studie specifiek op de hoog-risicogroep van vrouwen met excessieve gewichtstoename tijdens de voorgaande zwangerschap. Dit komt voor bij 40% tot 50% van alle zwangere vrouwen.

Een gezonde leefstijl is, ongeacht het gewicht, gerelateerd aan betere gezondheidsuitkomsten. Daarnaast is leefstijlverbetering een eerste stap richting gewichtsreductie. In Hoofdstuk 5 evalueerden we of de postpartum fase van de INTER-ACT leefstijlinterventie effect had op eetgedrag, energie-inname, fysieke activiteit en sedentair gedrag. Aan het eind van de postpartum interventie (6 maanden postpartum) had de interventiegroep een hogere score voor restrictief eten, een lagere score voor ongecontroleerd eten en een lagere energie-inname vergeleken met de controlegroep. Deze

verschillen hielden 6 maanden na de interventie geen stand, uitgezonderd de restrictief eten score onder vrouwen met een normaal BMI: die bleef hoger in de interventiegroep dan in de controlegroep. In de subgroep van vrouwen met overgewicht vonden we 6 maanden na de interventie een hogere score voor ongecontroleerd eten in de interventiegroep vergeleken met de controlegroep, hoewel er geen verschil was aan het eind van de interventie. Deze onverwachte bevinding kan worden toegeschreven aan een terugval naar beginwaardes in plaats van aan een negatief interventie-effect. De leefstijlinterventie had geen effect op de score voor emotioneel eten, fysieke activiteit en sedentaire tijd in de algehele interventiegroep, noch in een van de BMI subgroepen.

Hierop volgend evalueerden we of de postpartum fase van de INTER-ACT leefstijlinterventie effect had op gewicht, vetpercentage en middelomtrek. Daarnaast onderzochten we of een leefstijlverbetering (oftewel het verlagen van energie-inname, ongecontroleerd eten, emotioneel eten, of sedentaire tijd; of het verhogen van restrictief eten of fysieke activiteit) aan het eind van de interventie was geassocieerd met meer gewichtsverlies of een grotere afname van vetpercentage of middelomtrek gedurende de interventie. In Hoofdstuk 6 beschrijven we het effect van de leefstijlinterventie op gewicht en lichaamssamenstelling. We vonden geen verandering in gewicht en lichaamssamenstelling tussen 6 weken en 6 maanden postpartum als gevolg van de leefstijlinterventie. Wel stelden we vast dat het verminderen van energie-inname en verlagen van ongecontroleerd eten beiden waren geassocieerd met een hoger gewichtsverlies en een grotere afname van vetpercentage en middelomtrek, vergeleken met deelnemers die deze leefstijlverbetering niet vertoonden. Daarnaast was een stijging van restrictief eten geassocieerd met een grotere afname van vetpercentage en middelomtrek, maar niet met gewichtsverlies. Er werden geen associaties gevonden tussen het verbeteren van emotioneel eten, fysieke activiteit of sedentair gedrag en gewicht en lichaamssamenstelling.

De bevindingen die beschreven worden in dit proefschrift kunnen een leidraad bieden voor toekomstige postpartum leefstijlinterventies. In Hoofdstuk 7 formuleerden we aanbevelingen voor de praktijk en voor toekomstig onderzoek. Naast een gezonde voeding en fysieke activiteit zou men zich ook moeten richten op eetgedrag in toekomstige programma's. Echter, causaliteit tussen eetgedrag, voedingsinname en gewicht en lichaamssamenstelling moet verder opgehelderd worden in toekomstig onderzoek. Sedentair gedrag is ook een leefstijlfactor die nog weinig bestudeerd is in het postpartum. Effectieve strategieën om sedentaire tijd te verminderen in het postpartum en het effect daarvan op gewicht zou verder

onderzocht moeten worden. Op dit moment bestaat er geen core outcome set (kernresultaten set) voor postpartum leefstijlinterventies. De ontwikkeling en het gebruik van een dergelijke core outcome set zou de vergelijkbaarheid tussen studies verhogen en zorgt ervoor dat de uitkomsten die worden gemeten als relevanter ervaren worden door alle betrokkenen. Tenslotte zouden de lange-termijn effecten van deze postpartum leefstijlinterventie onderzocht moeten worden op de gezondheid en gewicht van de moeder en op de complicaties in een volgende zwangerschap.



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Climb every mountain,
ford every stream,
follow every rainbow,
till you find your dream.

- The Sound of Music



About the author

Margriet Bijlholt was born on 30 January 1990 in Amersfoort, the Netherlands. She completed her Bachelor's degree in Nutrition and Dietetics at the The Hague University of Applied Sciences in 2013. Subsequently, Margriet took the pre-master's program Health Sciences at the Vrije Universiteit Amsterdam followed by the research master's program Global Health. After graduating in 2016, Margriet started her joint PhD project at the University of Antwerp and the KU Leuven under supervision of her promotors Prof Roland Devlieger and Prof Annick Bogaerts and her co-promotor Dr Lieveke Ameye. In this position she worked on the Inter-pregnancy Lifestyle for a Healthy Future (INTER-ACT) trial, the results of which can be read in this thesis. Since January 2022, Margriet works as a lecturer at the Inholland University of Applied Sciences in Amsterdam.

