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SUPPORTING WEIGHT MANAGEMENT OF PREGNANT WOMEN WITH OVERWEIGHT: WEARABLE INTERNET-OF-THINGS INTERVENTION

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To my dear daughters,
Jannika and Jenny-Stina

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ABSTRACT

This study aimed to develop an intervention to support weight management of women with overweight during pregnancy and the postpartum period and to evaluate the feasibility of the intervention. The study was conducted in two phases: development and feasibility.

The development phase included two substudies: (1) A mixed method, descriptive study examined perceptions of weight management support among maternity care professionals (n=5) and pregnant women with overweight (n=11). (2) A prospective observational study summarized the feasibility of the Wearable Internet-of-Things-based system to continuously monitor the health parameters among pregnant and postpartum women (n=20). The data collected during the development phase were used to model a weight management intervention and implementation strategies with a cocreation approach. The intervention's core components were: (1) health technology; (2) motivational interviewing; (3) goal setting; and (4) feedback. The feasibility phase consisted of a quasi-experimental trial to assess the effectiveness of the weight management intervention in terms of improving self-efficacy in eating and physical activity and preventing gestational weight gain among pregnant women with overweight (n=54). Fidelity, acceptability, and adherence to the intervention were also evaluated.

The results showed that the intervention had no effect on a change in self-efficacy or weight gain. However, the importance of recommended gestational weight gain on better postpartum weight management was highlighted. In addition, women with signs of depression or women who had a lower educational level were found to have lower self-efficacy compared to women with no signs of depression or women who had a higher educational level. The inconsistency in adherence to the intervention implementation probably contributed to its lack of effectiveness. This study serves as a starting point for further research, emphasizing the need for more robust research designs and improved implementation strategies to enhance effectiveness.

KEYWORDS: health behavior; obesity, maternal; perinatal care; pregnancy; self-efficacy; wearable sensors; weight control; intervention study

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TIIVISTELMÄ

Tutkimuksen tarkoituksena oli kehittää ja arvioida terveysteknologiaa hyödyntävä painonhallintainterventio ylipainoisille naisille raskausaikana ja synnytyksen jälkeen. Tutkimus toteutettiin kaksivaiheisena: kehittämis- ja toteutettavuusvaihe.

Kehittämisvaihe sisälsi kaksi osatutkimusta. 1) Kuvailevassa monimenetelmätutkimuksessa selvitettiin äitiyshuollon ammattilaisten (n = 5) ja ylipainoisten raskaana olevien naisten (n = 11) painonhallinnan tukemiseen liittyviä käsityksiä. 2) Prospektiivisessa havainnointitutkimuksessa kuvattiin puettavaa teknologiaa hyödyntävän järjestelmän käytettävyyttä raskaana olevien naisten (n = 20) terveysparametrien jatkuvaan seurantaan. Kehittämisvaiheessa kerättyjen tietojen avulla mallinnettiin painonhallintainterventio ja toteutusstrategiat yhteistyössä äitiysneuvolan ammattilaisten ja ylipainoisten odottajien kanssa. Intervention keskeiset komponentit olivat 1) terveysteknologia, 2) motivoiva haastattelu, 3) tavoitteen asettelu ja 4) palaute. Tutkimuksen toisessa vaiheessa arvioitiin intervention toteutettavuutta kvasikokeellisella tutkimusmenetelmällä arvioimalla intervention vaikuttavuutta ylipainoisten odottajien (n = 54) syömisen ja liikunnan minäpystyvyyden lisäämiseen ja liiallisen raskaudenaikaisen painonnousun ehkäisemiseen. Lisäksi toteutettavuutta arvioitiin käyttöuskollisuuden, hyväksynnän ja intervention noudattamisen perusteella.

Interventiolla ei ollut vaikutusta minäpystyvyyden muutokseen tai painonnousuun, johtuen todennäköisesti epäonnistuneesta implementaatiosta ja intervention vaihtelevasta hyödyntämisestä neuvolakäynneillä. Raskausajan painonnousun pysyminen suositusten mukaisena kuitenkin edisti synnytyksen jälkeistä painonhallintaa. Lisäksi havaittiin, että jo lievästi masennusoireiset tai alemman koulutustason omaavat naiset kokivat minäpystyvyyden matalammaksi verrattuna ei-masennusoireisiin tai korkeasti koulutettuihin naisiin. Tämä tutkimus toimii lähtökohtana jatkotutkimuksille, korostaen tarvetta vahvemmille tutkimusasetelmille ja tehokkaammille implementaatiostrategioille.

AVAINSANAT: terveyskäyttäytyminen; ylipaino; raskaus; lapsivuodeaika; minäpystyvyys; puettava teknologia; painonhallinta; interventiotutkimus

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Abbreviations

APEASE	Affordability, Practicality, Effectiveness (and Cost-Effectiveness), Acceptability, Side effects and Safety, Equity
BCT	Behavior change technique
BCW	Behaviour change wheel
BMI	Body mass index
CFIR	Consolidated Framework for Implementation Research
COM-B	Capability, Opportunity, Motivation - Behavior
CBT	Cognitive behavior therapy
EPDS	Edinburgh postnatal depression scale
ERIC	Expert Recommendations for Implementing Change
GDM	Gestational diabetes mellitus
GWG	Gestational weight gain
HR	Heart rate
IOM	The Institute of Medicine
MI	Motivational interview
MRC	Medical Research Council
MVPA	Moderate to vigorous physical activity
OB	Obese
OW	Overweight
PA	Physical activity
PHN	Public health nurse
PICO	Population, Intervention, Comparison, Outcome
PPWL	Postpartum weight loss
PPWR	Postpartum weight retention
RQ	Research question
SLIM	Supporting Lifestyle Change in Obese Pregnant Women through Wearable Internet-of-Things
PASE	Physical activity self-efficacy
TiDieR	Template for Intervention Description and Replication
TDF	Theoretical Domains Framework
THL	The National Institute of Health and Welfare

UK	United Kingdom
WEL	Weight efficacy lifestyle
WIoT	Wearable Internet-of-Things
WHO	World Health Organization

List of Original Publications

This dissertation is based on the following original publications, which are referred to in the text by their Roman numerals I–IV:

I Saarikko J, Niela-Vilén H, Rahmani AM, Axelin A. Identifying target behaviors for weight management interventions for women who are overweight during pregnancy and the postpartum period: a qualitative study informed by the Behaviour Change Wheel. *BMC Pregnancy Childbirth*. 2021 Mar 11;21(1):200. doi: 10.1186/s12884-021-03689-6.

II Saarikko J, Niela-Vilen H, Ekholm E, Hamari L, Azimi I, Liljeberg P, Rahmani AM, Löyttyniemi E, Axelin A. Continuous 7-Month Internet of Things-Based Monitoring of Health Parameters of Pregnant and Postpartum Women: Prospective Observational Feasibility Study. *JMIR Form Res*. 2020 Jul 24;4(7):e12417. doi: 10.2196/12417.

III Saarikko J, Axelin A, Huvinen E, Rahmani AM, Azimi I, Pasanen M, Niela-Vilén H. Supporting lifestyle change in obese pregnant mothers through the wearable internet-of-things (SLIM) -intervention for overweight pregnant women: Study protocol for a quasi-experimental trial. *PLoS One*. 2023 Jan 19;18(1):e0279696. doi: 10.1371/journal.pone.0279696.

IV Saarikko J, Axelin A, Huvinen E, Rahmani AM, Kolari T, Niela-Vilén H. Effectiveness of supporting lifestyle change in pregnant mothers with obesity through the wearable internet-of-things (SLIM) -intervention on self-efficacy in weight management in pregnant women: A quasi-experimental trial. *Midwifery*. 2024 Nov 9; 140: 104235. doi:10.1016/j.midw.2024.104235

1 Introduction

The perinatal period, encompassing pregnancy and the postpartum phase, is a transformative and sensitive time in a woman's life. Throughout this journey, women experience profound physical and emotional changes. Pregnancy-related weight gain, coupled with the pressures of returning to a healthy weight postpartum, can be a daunting task with far-reaching implications for maternal and infant health, and for women with obesity, this period presents even more unique challenges. (Stubert et al., 2018; WHO, 2022.) In addition, obesity is associated with substantial risks during pregnancy, childbirth, and the postpartum period. When I worked as a midwife many years ago, I observed firsthand these challenges and risks that women were struggling with. During my master's studies, I became interested in the possibilities that technology offers to maternity care, and I completed my thesis as part of a research project that focused on the continuous monitoring of physical activity, sleep, and heart rate of pregnant women. I have been working with the same excellent research team ever since. These elements have formed the foundation of my doctoral studies.

In Finland, uniform quality and service level of maternity and child health clinic services are ensured by government decree (338/2011), which establishes the standards for services provided by maternity and child health clinics, ensuring comprehensive care for pregnant women, including the monitoring of maternal weight and guidance on healthy lifestyle practices. The National Institute of Health and Welfare (THL) supports municipalities in implementing national policies, including health promotion services. THL is responsible for public health initiatives, including maternal and child health. The institute operates programs aimed at improving prenatal care, monitoring maternal health outcomes, and supporting pregnancies. Pregnant women receive free care from public maternity clinics, including regular health check-ups, nutritional advice, and psychological support (THL, 2024). Public health nurses (PHN) in maternity clinics provide support and guidance to pregnant women regarding weight, sleep, physical activity (PA), and nutrition (Hakulinen et al., 2023).

Obesity is a global health concern, affecting a substantial proportion of women of reproductive age (15–49 years) (Poston et al., 2016; WHO, 2022). Maternal

obesity also incurs significant direct medical costs, indirect economic impacts, and long-term societal costs (Tremmel et al., 2017). The most common reasons for excessive gestational weight gain (GWG) include prepregnancy overweight or obesity. Additionally, lifestyle factors such as diet, PA, sleep patterns, and sociodemographic elements are significant contributors. (Suliga et al., 2018; Kouba et al., 2024.) Obesity and excessive GWG can complicate pregnancy, increasing the risk of health issues such as gestational diabetes, hypertension, preterm birth, and caesarean sections (Farpour-Lambert et al., 2018). Furthermore, obesity and excessive weight gain during pregnancy can lead to adverse outcomes, including macrosomia and birth complications as wells as a higher likelihood of postpartum weight retention (Mannan et al., 2013; WHO, 2022). These factors contribute to the long-term health challenges of mothers and their children. Addressing maternal obesity through comprehensive prevention and intervention strategies is essential not only for improving maternal and child health outcomes but also for reducing the economic burden on society.

In monitoring health-related behaviors, wearable technology offers the potential to provide real-time data on health parameters relevant to weight management (Berry et al., 2021). Wearable technology, including fitness trackers, smartwatches, and other health monitoring devices, has drawn attention to its potential to support individuals in their pursuit of healthier lifestyles (Zahrt et al., 2023). These devices offer various functionalities, such as monitoring PA, tracking nutrition, and providing real-time health data. For women with overweight or obesity, wearable technologies represent a valuable and cost-effective tool for actively engaging with their health, monitoring their progress, and making informed decisions about weight management during the perinatal period (Leblalta et al., 2022; Raichle et al., 2018).

The perinatal period places distinct demands on women with overweight or obesity. Emotional factors could hinder their ability to commit to behavior changes. Cultural norms, social support networks, and stigma play significant roles in shaping women's engagement for maternal weight management. Addressing these factors through inclusive design is essential for maximizing the adoption and effectiveness of weight management interventions (Mannan et al., 2013; Stubert et al., 2018). Therefore, effective strategies to support weight management in this vulnerable population are urgently needed. Weight management strategies during this time must be carefully tailored to mitigate potential risks while promoting a healthy pregnancy and postpartum recovery. Effective perinatal weight management should provide support to boost self-efficacy and behavior change and focus on the long-term alteration of habits and behaviors with strategies such as self-monitoring and positive reinforcement (Samdal et al., 2017). By creating a supportive and accepting environment, we can enhance the motivation and willingness of change, ultimately improving health outcomes for mothers and their children.

This dissertation aims to investigate and analyze the role of Wearable Internet-of-Things intervention to support weight management among women who are overweight or obese during the perinatal period, which in this study is defined as the timeframe spanning from pregnancy through the first 12 weeks following childbirth. The starting point of the study was the need to explore how wearable technology can be utilized in maternal care to support weight management, health, and well-being of women with overweight. To contribute to a more comprehensive understanding of the potential benefits and challenges associated with the use of Wearable Internet-of-Things as a part of interventions in perinatal weight management, it is important to understand the use of wearable technology in maternity care settings and to assess the acceptance and usage patterns of wearable devices among pregnant and postpartum women in general. Ultimately, the findings of this dissertation inform evidence-based practices and intervention that can improve the health and well-being of women with overweight during pregnancy and the postpartum period by developing, targeting, and implementing weight management interventions for maternity clinics.

2 Background

2.1 Weight management of women with overweight or obesity during perinatal period

Weight management is defined as the process of implementing long-term lifestyle modifications to maintain a healthy body weight. This typically involves a combination of a balanced diet, regular physical activity, and behavioral changes. (WHO, 2024.) Weight management during the perinatal period is important for the health and well-being of women and their children. Weight management aims not only to achieve an ideal weight but also to prevent weight-related health issues and improve overall well-being. It can reduce the risk of maternal complications as well as complications for the unborn child (Buckingham-Schutt et al., 2019; WHO 2024). Weight management during the perinatal period can also establish a foundation for women's long-term health and mitigate the risk of obesity-related problems later in life (Aung et al., 2022; Lihavuus: Käypä hoito-suositus, 2024). Regular antenatal appointments in maternity clinics enable the continuous collaboration between maternity care professionals and pregnant women and include weight management interventions when necessary (I-WIP, 2017). It is crucial to support and encourage women's motivation to take care of their own and unborn child's health during this exceptional period in their life.

2.1.1 Burden of maternal obesity and excessive gestational weight gain

Overweight, defined as a prepregnancy body mass index (BMI) between 25 to 29.9 kg/m^2, and obesity (BMI 30 kg/m^2 or more) among women of reproductive age has become a global health concern (WHO, 2022). In Finland, 44.3% of pregnant women were overweight and of these, 18.0% were obese in 2021 (THL, 2023). These numbers keep rising constantly. Obesity is a pervasive global health epidemic. In the United Kingdom, almost 50% of pregnant women were obese in 2018 and the cumulative prevalence of overweight or obese adults is predicted to reach 70% by 2034 (NHS, 2018). Obesity is no longer exclusively the western world's problem, and it is not a new challenge, although the extent of the problem at present is

unequaled. In addition, the consequences of obesity are indisputably challenging to modern obstetrics. (Kominiarek et al., 2018.)

Obesity and excessive GWG have several negative consequences for both mother and child. It is essential for pregnant women and maternity care professionals to be aware of these risks. Pregnant women with obesity have an increased risk of pregnancy complications, miscarriage, excessive GWG, antenatal and postnatal depression, and gestational diabetes mellitus (GDM). GDM and obesity are also associated with a higher risk of type 2 diabetes later in life.

In addition, women with overweight or obesity have the higher risk of hypertensive disorders such as gestational hypertension and pre-eclampsia. These may lead to complications for mother and the child, stillbirth, and postpartum hemorrhage. (Wu et al., 2022.) In addition, excessive GWG increases the risk for caesarean sections and surgical complications. Excessive GWG is also associated with postpartum weight retention, which may predispose women to an elevated risk of cardiometabolic diseases and obesity in subsequent years. Excessive GWG can contribute to long-term weight management challenges, obesity, and related health problems in the future (Kominiarek et al., 2018; Nightingale et al., 2023). Obesity and excessive GWG are also a significant risk for the child. Both independently increase the risk of infant adiposity, macrosomia, birth complications and glucose, insulin and cardiometabolic dysregulation in the offspring. In addition, the children are more likely to become overweight later in later (WHO, 2022). Maternal obesity is also associated with congenital fetal malformation, preterm birth, and postpartum mortality (Poston et al., 2016).

2.1.2 Weight-related guidelines and recommendations in maternity care – a historical review

Remarkable changes in gestational weight gain recommendations have occurred over the past century. The maternal diet was highlighted as the only source of nutrition for the unborn child between the 16th and 18th centuries (Rosso & Cramoy, 1979). In the 19th century, overeating became a detrimental theme, which was believed to cause large babies and difficult labor. Limiting an offspring's size by restricting maternal food intake formed the basis for the first published study of diet and pregnancy. In the 1920s, maternal weight gain was reported to be a good indicator of maternal nutrition status and fetal growth (Davis, 1923). Documentation of GWG became an increasingly common clinical practice. At first, excessive weight gain was interpreted as a sign of edema and incipient toxemia. Women were typically guided to limit their GWG to 6.8 kg (Bingham, 1932; McIlroy & Rodway, 1937). Most published studies of GWGs reported average gains of less than 9.1 kg (Hytten, 1980). During the 1950s and 1960s, large studies of gestational weight gain

concluded that an average gain of 12.5 kg is normal in healthy, young, primigravid women (Billewicz & Thomson, 1957; Eastman & Jackson, 1968; Humphreys, 1954; Singer et al., 1968). During the 1970s and 1980s, several recommendations of maternal nutrition and GWG were published (AAP/ACOG, 1983; NRC, 1970, 1974, 1981; Pitkin 1970 and 1977). Current guidelines and recommendations to GWG are based on prepregnancy BMI (IOM, 2009; AOCG, 2013). Recommendations for women who are overweight (prepregnancy BMI ≥25) are 7–11 kg and for women with obesity (BMI ≥30) 5–9 kg during pregnancy. In Finland, national weight gain recommendations are consistent with international guidelines (Lihavuus: Käypä hoito-suositus, 2024). According to a systematic review and meta-analysis, conducted between 1999 and 2017, only about a fifth (23%) of women with overweight and 21% of women with obesity gained weight within recommendations. Over half of women with overweight gained more weight than recommended. Weight gain above the recommendations was highest among women who were overweight (64%) or obese (60%) before pregnancy (Goldstein et al., 2017 and 2018). In addition, there is an ongoing debate about lowering the weight gain recommendations for pregnant women with obesity. Some studies suggest that weight gain below these recommendations, or even weight maintenance, might be safer and more beneficial for women with obesity (Kapadia et al., 2015; Comstock 2019).

2.1.3 Maternity care and perinatal weight management in Finland

In Finland, women receive free care at maternity clinics during the perinatal period. Women meet with registered PHNs or registered midwives regularly; nullipara women have at least nine and multipara women at least eight appointments during pregnancy. After birth, women are offered one home visit and one medical check-up. In addition to regular appointments, women are offered additional appointments if needed. The utilization of public maternity care services is predominant among pregnant women due to their high accessibility and excellent quality. Extensive use of public services ensures comprehensive perinatal care for all women. While private maternity care services are available, they are utilized by only a small fraction of the population (THL, 2023).

Weight assessment is integrated into routine prenatal care to identify deviations from the expected trajectory and to urge pregnant women to gain weight within recommended guidelines. Pregnant women are also provided with support for a healthy lifestyle and overall well-being, which includes guidance on nutrition and regular, moderate-intensity PA during pregnancy, unless there are specific medical contraindications to ensure a healthy pregnancy for both mother and child (THL,

2020; UKK-instituutti, 2021; NRF, 2022). During the postpartum period, women are offered recommendations for postpartum weight management, healthy eating, and PA (NRF, 2022; THL, 2020). Postpartum women are particularly vulnerable to weight retention and often need support to maintain a healthy lifestyle. Weight management support during pregnancy alone is often insufficient for eliciting sustained change in health behaviors. The transition to the postpartum period brings an additional set of challenges to maintain healthy behaviors due to the demands of childcare, and women may not receive adequate support for weight management from maternity clinics because the focus often shifts to the child's care and well-being (Walker et al., 2019).

2.1.4 Behavior change, self-efficacy, and the relation to perinatal weight management

Behavior change is a significant concept in health promotion and also in perinatal weight management. Behavior change refers to altering habits and behaviors for the long term. It can be defined as a systematic process of modifying behaviors through interventions aimed at altering an individual's actions, attitudes, habits, and environmental influences through observational learning, self-efficacy, and reinforcement. Behavior change typically employs strategies like goal-setting, self-monitoring, and social support to achieve and sustain targeted behavioral outcomes (Bandura, 1986; Davis et al., 2015). The primary factors contributing to weight management issues often extend beyond excessive caloric intake or insufficient PA. Weight management is strongly associated with one's own resources, coping mechanisms, and skills in regulating emotional and attention levels. Weight gain often results from a combination of factors; for example, poor dietary habits, lack of PA, and emotional eating. Long-term weight management requires adopting and maintaining healthy habits. By focusing on behavior change, women can create a healthier lifestyle that supports long-term weight management and overall well-being. Successfully changing behaviors enhances self-efficacy and confidence in one's ability to manage weight, which can lead to further positive changes and a greater sense of control over one's health (Michie et al., 2014; Teixeira et al., 2015).

Bandura's Social Cognitive Theory emphasizes the interplay between personal factors, environmental influences, and behavior in determining behavior change (Bandura, 1977). Self-efficacy as a central component of Bandura´s Social Cognitive Theory, emphasizing the learning that occurs in a social context, has been identified as an important determinant of health behavior, and in turn, health behavior change. Self-efficacy can be defined as an individual´s particular set of beliefs that determine how well one can execute a plan of action in prospective situations (Bandura, 1977). Self-efficacy is an important factor that influences behavior change in many behavior

change theories such as Health Belief Model (Rosenstock et al., 1988), Theory of Planned Behavior (Ajzen, 1991), and Behaviour Change Wheel (Michie et al., 2011). These theories have been used as a comprehensive foundation to understand and design interventions for behavior change in various contexts. Self-efficacy is a central element in the belief in one's ability to complete a task, and thus it is a crucial psychosocial factor that consolidates change in behavior (Zhu et al., 2013).

Self-efficacy and motivation to change play an essential role in perinatal weight management. Self-efficacy has been studied broadly as a psychosocial correlate and predictor of changes in weight and weight-related behaviors, and it has also been viewed as an essential target of change in behavioral weight loss interventions (Faghri et al., 2016). Self-efficacy has proven to be a strong predictor of PA, nutrition, and weight, and it is essential to set realistic and achievable weight management goals. In addition, individuals with high self-efficacy are more likely to monitor their dietary or PA behaviors accurately. Self-monitoring also provides important feedback, which can be used to adjust weight management behaviors (Annesi & Powell, 2023; Gallagher et al., 2012). Self-efficacy is also a crucial factor in relapse prevention (Samdal et al., 2017) and meeting GWG recommendations during pregnancy (Halili et al., 2019). Furthermore, higher self-efficacy has been associated with a decrease in body weight from early pregnancy to two years postpartum (Lipsky et al., 2016). A positive correlation between self-efficacy and the propensity to undertake beneficial behaviors exists. As self-efficacy increases, it enhances the likelihood of engaging in positive actions, and concurrently, the successful modification of behavior acts as a reinforcing mechanism that further increases self-efficacy (Bandura 1997). Self-efficacy and behavior change are of the utmost importance in health and well-being promotion, as they empower individuals to make healthier choices, improve mental health, and enhance the overall quality of life (Bandura 2004).

Pregnant women who are overweight or obese may have a history of healthcare professionals who have given advice without any knowledge about the women's former weight-loss attempts or background. This behavior may be perceived as offensive and make women feel underestimated, and thus it is counterproductive (Holton et al., 2017; Christenson et al., 2019). Women's own beliefs about their individual ability to control their weight may influence their interest in receiving information and increase the risk of becoming offended by caregivers who broach the topic of body weight. The complexity of weight change should be well understood by healthcare professionals in order to reduce the stigma about weight and facilitate communication about gestational weight gain (Christenson et al., 2019). Effective perinatal weight management should include providing support and strategies for boosting self-efficacy while promoting behavior change for healthy weight management. Behavior change techniques such as health education, goal

setting, positive reinforcement, and self-monitoring are feasible boosters to enhance self-efficacy (Olander et al., 2013; Samdal et al., 2017). In the era of digitalization, Wearable Internet-of-Things (WIoT) may serve as a valuable self-monitoring tool for reinforcing positive behaviors. It may encourage pregnant women to track their eating habits, PA, and weight. It may also increase awareness and help identify areas for improvement.

2.2 Wearable Internet of Things in maternity care

Between 2019 and 2022, wearable technology has increased substantially. In 2022, the number of wearable devices reached 1.1 billion, up from 722 million recorded in 2019 (Statista, 2023). Consumer electronics applications led the global wearable technology industry in 2022 and is predicted to continue its growth. Healthcare is predicted to experience the second-fastest growth rate from 2022 to 2030 because the increasing scope of wearable devices in the pharma sector will support the growth during the forecast period (Market analysis report, 2023).

WIoT is defined as a technological infrastructure that interconnects a wearable sensor to monitor parameters such as health, wellness, and behaviors that are useful in enhancing an individual's overall quality of life. WIoT devices connect personal body area sensors to the medical infrastructure so that physicians, for example, can perform longitudinal assessments of their patients when they are at home (Mamdiwar et al., 2021). WIoT-based monitoring infrastructure includes three main components (**Figure 1**): (1) Body area sensors that collect the data of health-related parameters and connect it to networks via Wi-Fi or Bluetooth; (2) Internet-connected gateways to transmit data, and (3) Cloud and big data support that offer data processing capabilities and advanced analytics including machine learning and artificial intelligence (Surantha et al., 2021). In practice, individuals wear sensors, such as smartwatch or smart ring that monitor health-related parameters, enabling individuals and healthcare professionals to track the data through web-based user

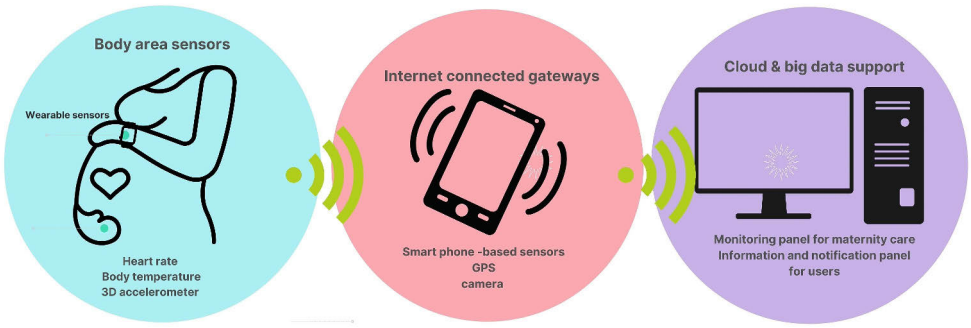


Figure 1. Architectural elements of Wearable Internet-of-Things in maternity care.

interfaces anywhere and anytime. Continuous data can be supplemented with smartphone applications such as an electronic food diary or different health applications. WIoT-based systems have also been utilized to provide ubiquitous maternal health monitoring during pregnancy and postpartum. The system consisted of various data collectors that tracked the mother's condition, including sleep and PA (Sarhaddi et al., 2021). The combination of continuous data collection from smartphone applications, advanced machine learning, and artificial intelligence techniques can revolutionize healthcare and wellness in the future because it enables early detection of health issues, personalized interventions, and improved management of one's health (Subhan et al., 2023; Surantha et al., 2021). However, there are several significant challenges related to wearable data processing, privacy, security, and transmission that need to be carefully considered in the development and use of wearable technology (Subhan et al., 2023).

Interoperability, which is related to the data exchange between heterogeneous devices and communication protocols, faces diverse challenges. It is important to manage the integral heterogeneity of WIoT systems and ensure efficient solutions for smooth interoperability among smart devices and sensors (Ometov et al., 2021). In addition, the variability of sensors and inconsistency of data collection complicates the quality assessment. For example, the measurement of oxygen saturation can vary significantly based on the location of the measurement and types of devices (e.g., watches, rings, and earphones). Erroneous detection and prediction of wearable devices can create unnecessary stress in users, raising concerns for health and hampering the implementation. Data quality assessment is an ongoing process that requires vigilance and the integration of techniques and technologies to address the variability and inconsistency inherent in sensor data collection (Canali et al., 2022; Ometov et al., 2021). Finally, a unified solution to address all threats to wearable technology security does not exist and needs thorough consideration. The security and privacy aspects for wearable devices are complex and evolving. They require careful and continuous consideration and a multifaceted security strategy that takes into account the specific context and risks associated with wearable technology, organizations, and manufacturers (Mamdiwar et al., 2021; Ometov et al., 2021; Subhan et al., 2023).

2.2.1 Wearable Internet-of-Things in weight management

According to a recent systematic review and meta-regression, interventions utilizing wearable technology as intervention tools has proven to be effective in promoting weight loss and weight maintenance among adults (Wong et al., 2022) and inactive adults with overweight or obesity (McDonough et al., 2021). One systematic review and meta-analysis reported that wearable technology as a PA intervention in children

and adolescents was effective on obesity-related outcomes such as weight or body fat (Wang et al., 2022). In addition, digital self-monitoring of behavioral interventions such as eating habits and PA were an effective and possibly cost-effective method to promote weight loss in adults with overweight or obesity (Berry et al., 2021). Wearable technology can positively influence individuals' behavior and health (Zahrt et al., 2023). Technology-based interventions that integrated theory and incorporated different behavior change techniques (BCTs) and a variety of implementation strategies were found to be effective (Teixeira & Marques, 2018). A central aspect in the development and implementation of health behavior change intervention are the BCTs that are used to change someone's behavior and the modes of delivery of the intervention. Recently, the use of digital modes of delivery and the effective BCTs, such as self-monitoring, feedback, restructure of the environment, graded tasks and goal setting in lifestyle interventions have increased and seem promising (Carraça et al., 2021).

While WIoT offers numerous benefits for weight management it also causes some challenges. First, the usability of wearable devices plays a significant role in their adoption and adherence among users. For example, some types of devices are not comfortable enough to be worn all the time (Hu et al., 2020; Shin et al., 2019). In addition, social influence and confidence to receive support affect the adoption of wearable technology. Moreover, attitude, inattentiveness, adoption intention, compatibility, and self-image are common barriers toward adoption of wearable devices in weight management. Furthermore, anxiety, interpersonal influence, level of openness to change, lack of user satisfaction, loyalty to electronic devices, and lack of contentedness are perceived barriers. Recommendations and support from friends and family, education, and promotion of the benefits can be used to increase the adoption of the wearable technology-based weight management (Al-rawashdeh et al., 2022). Successful adoption of and adherence to wearable technology-based weight management interventions require user-centered design, customization to individual needs, effective BCTs, and a supportive environment (Al-rawashdeh et al., 2022; Hu et al., 2020).

2.2.2 Wearable Internet-of-Things in perinatal weight management

Information about pregnant women's lifestyle and behavioral patterns related to PA, sleep, and nutrition could help women with overweight and maternity care professionals identify various factors that maintain obesity and lead to negative pregnancy outcomes (Van den Heuvel, et al., 2018). Furthermore, the continuous monitoring of physiological parameters would help personalize interventions to minimize weight gain and adopt a healthier lifestyle during pregnancy. Physiological

parameters have already been used in maternity care to detect clinical conditions for a long time. For example, blood glucose is monitored regularly to diagnose possible GDM, and the recent use of various remote monitoring applications of blood glucose has increased resulting in a decreased number of maternity care visits for women with GDM with no differences noted in maternal or neonatal outcomes (Leblalta et al., 2022). In addition, high blood pressure, which might be a symptom of pre-eclampsia, is possible to measure with pulse and blood pressure sensors in a smartphone application, and the feedback from pregnant women has been positive (Raichle et al., 2018). By monitoring PA, sleep, and nutrition, it is possible to detect risk factors related to obesity, and wearable technology could provide methods for ubiquitous and continuous monitoring in maternity care.

In summary, perinatal weight management is crucial for the health of both mother and child. It may prevent a range of complications, promote healthy pregnancies and births, and support postpartum recovery. Guidelines aim to reduce the risk of complications with excessive GWG, and it is important for maternity care professionals to provide personalized guidance based on individuals' unique circumstances and medical history. Open and trusting communication in the relationship between pregnant women and maternity care professionals is essential to ensure that weight management aligns with the specific needs and goals for each woman. However, the current monitoring and counseling in maternity care are not sufficient to support engagement in weight management of women with overweight or obesity. Novel, personalized, and flexible methods adapted to a pregnant woman's everyday life are needed. Furthermore, a personalized approach could involve the partners and family in the pregnancy monitoring and increase commitment. Direct feedback from the application also enhances women's self-efficacy and self-management because it makes the woman more aware of her health and reinforces her commitment to pregnancy care. Utilizing women's personal lifestyle data during maternity care appointments to provide feedback and recommendations based on the data could increase women's motivation and commitment of the whole family to a healthy lifestyle and well-being. Since perinatal weight management, at its best, might contribute to lifelong well-being for mothers and children, maternity care professionals are in a key position to guide and support perinatal women's weight management efforts to ensure safe and healthy pregnancies. Overall, there is a need to synthesize extensive and complex evidence to provide a clear and actionable understanding of perinatal weight management interventions for women with overweight or obesity.

3 Umbrella Review of the Literature

3.1 Search strategy

The aim of the literature review was to provide an understanding about the perinatal weight management interventions for women with overweight and the utilization of technology in interventions. The review questions were: (1) What is the range of perinatal weight management interventions available for overweight women, and how is technology utilized in these interventions? (2) What are the needs and opportunities for future research in this area?

The methodology of an umbrella review was conducted because a large number of reviews in the field of weight management interventions for women with overweight during perinatal period have been conducted. An umbrella review was applied to combine findings of separate reviews and gather existing evidence in the broad topic area (Aromataris et al., 2015). A systematic search was conducted in six (6) electronic databases (PubMed, EBSCOhost, Cochrane Library, Scopus, Web of Science, and MEDIC) in 2018 and reiterated in July 2024. The search strategy followed the Population, Intervention, Comparison, Outcome (PICO) model (Stern et al., 2014). P: pregnant or postpartum women with overweight or obesity, or professionals working in maternity care; I: intervention, health promotion or education, or maternal behavior; C: usual care or no intervention; O: Body weight, GWG, weight management, healthy lifestyle. The extensive list of search terms was used to merge perinatal weight management interventions for women with overweight (Appendix 1. Databases, search queries and search results). All citations were exported into Zotero 6.0.26 and Mendeley citation software for screening and management. The systematic search was supplemented with manual searches from the reference lists of the included articles, but no other reviews or grey literature were included.

All reviews that reported on perinatal weight management or lifestyle interventions were included to gain an explicit view of the current literature. Target populations were women with overweight or obesity during the perinatal period or professionals working in perinatal care. Outcomes were weight related, maternal or infant related and/or psychosocial outcomes. All reviews included were published in English and had abstracts available. Studies aimed at modifying diet and/or exercise

during pregnancy for the sole purpose of improving or managing a specific disease (e.g., gestational diabetes) were excluded. Altogether 23 reviews were included. The flow of the literature is reported in **Figure 2** (Page et al., 2021).

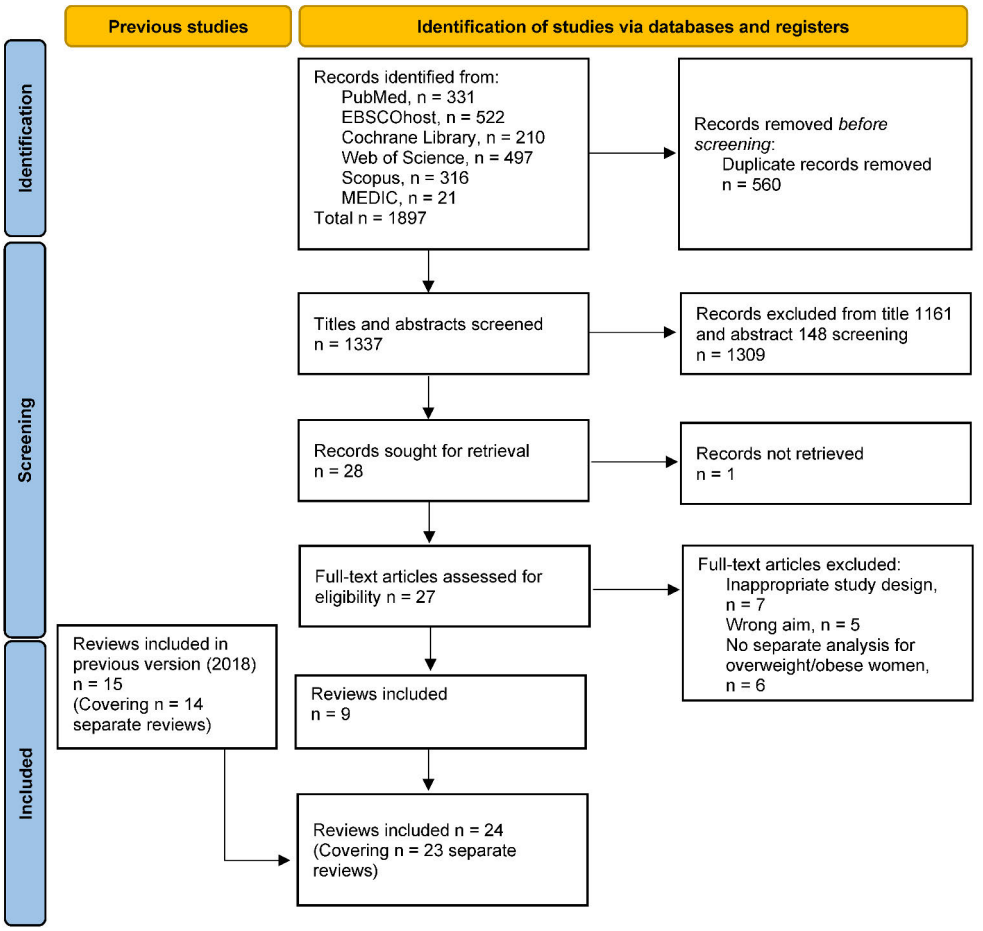


Figure 2. PRISMA 2020 flow diagram for updated systematic review of reviews.

3.2 Methodological quality of systematic reviews

All systematic reviews were critically appraised (Appendix 2. JBI Critical Appraisal Checklist for Systematic Reviews and Research Syntheses) (Aromataris et al., 2015). All reviews reported appropriate criteria for appraising studies, but in two reviews it was unclear if critical appraisal was conducted by two or more reviewers independently (Dalrymple et al., 2018; Dodd et al., 2010). Two reviews did not report undertaking data extraction in duplicate (Agha et al., 2014; Dodd et al., 2010).

All reviews that included meta-analysis justified its use and applied appropriate methods. However, six reviews (Brown et al., 2012; Dodd et al., 2010; Du et al., 2018; Shieh et al., 2018; Sui et al., 2012; Wu et al., 2022) did not report assessing the impact of the risk of bias within the included studies on the results of the meta-analysis. Overall, reviews were rated between seven (7) and 11, out of 11 points.

3.3 Description of included reviews

A total of 23 reviews (two reviews shared the same data and results) were published between 2010 and 2024 and met the inclusion criteria. The literature search revealed 14 meta-analyses of which two were network meta-analyses and nine were narrative reviews. Most reviews included a majority of trials conducted in North America, Australia, Europe, or the UK.

The 23 reviews comprised 502 original studies and involved between 276 and 16,615 perinatal women in all BMI categories. Most of the reviews included the same empirical studies, meaning that the real number of original empirical studies in this review was 178 (Appendix 3. The original studies of the literature review).

Participants were nulliparous and multiparous pregnant or postpartum women. Most antenatal studies recruited participants at less than 20 weeks gestation. The 23 reviews consisted of 19 reviews during pregnancy and four reviews during pregnancy and the postpartum period. In 15 reviews, only women with overweight or obesity were recruited. In the remaining eight reviews perinatal women irrespective of weight status were included, but subgroup analysis for women with overweight or obesity were provided. One review targeted maternity care professionals (seven studies involving 335 participants) in interventions focusing on the perinatal weight management of women with obesity (Appendix 4. Characteristics of the included systematic reviews).

3.4 Synthesis of findings

3.4.1 Perinatal weight management interventions

The interventions described in the reviews and the details provided were heterogeneous. Common characteristics of the interventions were diet, PA, or both. One review focused on dietary interventions (Lamminpää et al., 2018), and three reviews focused exclusively on PA interventions (Du et al., 2018; Flannery et al., 2019; Sui et al., 2012). One review included only e-based interventions (Lau et al., 2017), and most of the studies utilized technology components in their interventions. In a majority of systematic reviews, one or more psychobehavioral elements were utilized in the interventions. Two reviews focused on interventions incorporating

psychobehavioral components on GWG outcomes (Aung et al., 2022; Nightingale et al., 2023). The methods for follow-up varied considerably between studies. In addition, the duration of interventions varied substantially from one session to 70 weeks. All systematic reviews reported control groups—usual or standard care—as the comparison. The description of usual care within the studies in many systematic reviews was not specified.

Outcome measures in most reviews were weight related (e.g., GWG, postpartum weight loss (PPWL), or postpartum weight retention (PPWR)). Other outcomes reported were incidence of GDM and maternal or infant related outcomes such as gestational week of delivery, perinatal mortality, and infant birth weight. Three reviews reported psychobehavioral outcomes (Bernardo et al., 2024; Brown et al., 2012; McGovern et al., 2024). In addition, PA outcome measures, effective BCTs in improving PA levels (Flannery et al., 2019), and dietary outcomes (Flynn et al., 2016) were reported. One review focused on maternity care professional behaviors in managing perinatal obesity and/or GWG and promoting adherence to the GWG guidelines and other perinatal outcomes (Kominiarek et al., 2018). One review also reported intervention integrity (adherence, exposure, quality of delivery, participant responsiveness, program differentiation). However, the lack of process evaluations in the studies made it challenging to accurately evaluate how well the interventions were implemented (Brown et al., 2012).

3.4.1.1 Dietary and PA interventions

The reviews incorporated a versatile range of dietary interventions. Many studies included more than one dietary component including calorie restriction, personalized targets according to prepregnancy BMI, uniform advice on macronutrient goals, replacing carbohydrates with low-glycemic foods, reducing fat intake, increasing fruits, vegetables, fiber, fish, and vegetable oils intake, providing meal plans, portion sizes, and advice on adjusting dietary intake to activity levels, and dietary supplements of vitamins or a Mediterranean diet (Agha et al., 2014; Behnam et al., 2022; Bernardo et al., 2024; Brown et al., 2012; Choi et al., 2013; Dalrymple et al., 2018; Dodd et al., 2010; Du et al., 2018; Flannery et al., 2019; Flynn et al., 2016; I-WIP, 2017; Lamminpää et al., 2018; Lau et al., 2017; Shieh & Burke Draucker, 2018; Wu et al., 2022; Yu et al., 2024).

PA interventions within included reviews were also diverse. PA was mostly categorized as supervised or unsupervised, or a combination of the two. Supervised sessions included aerobic training (dance, treadmill walking) or resistance training (pelvic floor or large muscle training), or a combination of both. PA intensity was determined objectively through heart rate (HR) monitoring or subjectively by self-perceived exertion in some studies. Unsupervised PA interventions included

individual exercise plans with time and/or frequency goals, exercise videos, step count monitors, treadmills or home cycles, or six months of free gym memberships (Agha et al., 2014; Behnam et al., 2022; Brown et al., 2012; Choi et al., 2013; Dalrymple et al., 2018; Dodd et al., 2010; Du et al., 2018; Flannery et al., 2019; Flynn et al., 2016; I-WIP, 2017; Lau et al., 2017; Shieh et al., 2018; Sui et al., 2012; Wu et al., 2022; Yeo et al., 2016; Yu et al., 2024). Many studies included multicomponent interventions that incorporated aspects from both diet and PA interventions.

3.4.1.2 Psychobehavioral interventions

In three reviews, BCTs such as motivational interviewing, social support, goal setting or feedback to emphasize self-efficacy were utilized as part of the interventions (Agha et al., 2014; Behnam et al., 2022; Brown et al., 2012). Social cognitive theory was used in some studies as a framework. In addition, behavioral intervention components such as specific counseling techniques, cognitive behavior therapy techniques, and a behavior change program that was based on social cognitive theory were reported (Aung et al., 2022; Behnam et al., 2022; Kominiarek et al., 2018; Nightingale et al., 2023). One review described women's perspectives on mHealth tools for weight management and specific mHealth interventions comprised of webinars, smartphone applications, telemedicine, and health behavior change coaching (McGovern et al., 2024). One review consisted of studies that specifically targeted the maternity care professional in interventions that focused on the perinatal management of obesity or GWG (Kominiarek et al., 2018). One review found 19 different BCTs within the 19 intervention studies ranging between one (1) and 10 in each study. ”Self-monitoring of behavior” and ”Instruction on how to perform the behavior” were the most frequently described techniques across the interventions (76.5%). ”Information about health consequences” and ”social support” were used in over 40% of the interventions. The most commonly used BCT categories within the interventions were ”goals and planning,” ”feedback and monitoring,” ”social support,” ”shaping knowledge,” and ”natural consequences.” Interventions including these BCTs showed positive effects in improving PA levels (Flannery et al., 2019).

3.4.2 Content and delivery of the interventions

Most interventions were delivered through in-person counseling sessions either individually or in a group. Counseling was usually provided by nutritionists, dieticians, midwives, primary care providers, or other healthcare professionals. In addition, interventions were delivered remotely via websites, applications, text

messages, email, Facebook groups, or support forums (Agha et al., 2014; Aung et al., 2022; Behnam et al., 2022; Brown et al., 2012; Choi et al., 2013; Dalrymple et al., 2018, 2018; Flannery et al., 2019; Flynn et al., 2016; Lamminpää et al., 2018; Lau et al., 2017; Nightingale et al., 2023; Shieh et al., 2018; Wu et al., 2022; Yeo et al., 2016). Successful interventions included technology-based strategies or a combination of face-to-face and technology-based approaches (Dalrymple et al., 2018). One meta-analysis of seven RCTs reported that e-based interventions incorporating in-person or phone delivery were more effective for reducing GWG than solely e-based platforms (Lau et al., 2017).

Many interventions involved written information and utilized diaries to encourage women to set goals to change their diet. Some women were given diaries or pedometers to self-monitor PA (Behnam et al., 2022; Choi et al., 2013; Dalrymple et al., 2018; Du et al., 2018; Flynn et al., 2016; Lau et al., 2017; Nightingale et al., 2023; Wu et al., 2022). Some interventions included memberships to fitness centers, individual exercise plans, or supervised programs (Behnam et al., 2022; Choi et al., 2013; Dalrymple et al., 2018; Du et al., 2018; Shieh et al., 2018).

A recent network meta-analysis of 60 RCTs compared the delivery strategies of interventions. Altogether 20 studies reported remote delivery mode, 29 studies reported face-to-face delivery mode, and 11 studies reported mixed delivery mode. The results highlighted that the unique attributes of pregnancy necessitate face-to-face sessions for consistent and direct monitoring of weight changes and alterations in diet, PA, and behavior. Such sessions afford instantaneous feedback that aids pregnant women in implementing crucial adjustments to their diet and PA routines (Yu et al., 2024). One review reported extra time with a midwife during an antenatal visit as part of an intervention. The roles of maternity care professionals were highlighted in weight management interventions in four reviews (Aung et al., 2022; Lamminpää et al., 2018; McGovern et al., 2024; Yeo et al., 2016).

3.4.3 Effectiveness of dietary and PA interventions

The summary of the effects of perinatal interventions on weight change are presented in **Table 1**, and the results of narrative reviews are described in **Table 2.**

A network meta-analysis of 60 RCTs (n=16,615 pregnant women with overweight) and a review of 13 RCTs (n=4,276 pregnant women with overweight) reported significant reduction in GWG in the diet intervention groups compared to controls (Flynn et al., 2016; Yu et al., 2024). On the contrary, a review of seven trials (n=743 pregnant women with overweight) reported that dietary interventions were not effective on reducing GWG of women with overweight or obesity (Dodd et al., 2010).

A meta-analysis including 23 RCTs (n=11416 pregnant women with overweight) reported that dietary interventions alone were not effective on the reduction of GWG. However, PA interventions and combined diet and PA interventions significantly reduced GWG. In addition, the numbers of women with excessive GWG were significantly lower in PA groups and combined intervention groups compared with the control group (Behnam et al., 2022). In addition, a meta-analysis of 14 studies (n=1771 women) (Agha et al., 2014) and a meta-analysis of 21 RCTs (n=6,920 women with overweight or obesity) resulted in a significant reduction in GWG in diet and/or PA intervention groups compared to control groups. Subgroup analyses revealed that four diet RCTs demonstrated significant reduction in GWG in the intervention group. Six PA trials did not produce significant reduction in GWG. Eleven combined PA and diet RCTs were significantly effective in reducing GWG (Shieh et al., 2018). Similarly, a meta-analysis of 11 RCTs (7 RCTs, n=721 pregnant women and 4 RCTs n=547 postpartum women with overweight or obesity) reported significant reduction of GWG in supervised PA intervention and combined PA and diet intervention groups compared to control groups (Choi et al., 2013). On the contrary, an integrative review concluded that diet and PA interventions were ineffective in reducing GWG (Aung et al., 2022). In addition, a meta-analysis (n=5,418 pregnant women with overweight) concluded that only nine out of 32 trials reported significant reduction in GWG in diet and/or PA intervention groups compared to control groups (Yeo et al., 2016).

A meta-analysis of 13 RCTs (n=1,439 women with overweight and obesity) (Du et al., 2018), a meta-analysis of 15 studies (n=6,812 women with overweight or obesity)(Kuang et al., 2023), and a meta-analysis of five trials (n=216 women with overweight or obesity) (Sui et al., 2012) reported that PA interventions significantly reduced GWG. A meta-analysis of individual participant data of 33 RCTs (n=9,320 women) also found that diet and PA interventions significantly reduced GWG (I-WIP, 2017). In a review of 15 studies, 10 studies reported significant differences between dietary and PA intervention groups and controls in limiting the GWG. The remaining five studies reported no significant difference between the groups (Lamminpää et al., 2018).

Moreover, Bernardo et al. (2024) found in their review of six studies (n=2,684 pregnant women with overweight or obesity) that dietary counseling and PA interventions did not significantly affect quality of life compared to standard prenatal care. However, better adherence to the intervention was linked to improved physical quality of life post-intervention. Additionally, greater gestational weight gain was associated with worsened mood, increased depressive symptoms, and lower physical health-related quality of life during pregnancy compared with standard prenatal care. PA interventions were also found to reduce the risk of complications such as GDM, macrosomia, and caesarean sections in overweight and obese pregnant women in a

review of 19 studies (Flannery et al., 2019; Kuang et al., 2023), and similarly with a meta-analysis of individual participant data (I-WIP, 2017). Behnam et al. (2022) reported that 22 RCTs of behavioral therapy supported PA, and diet interventions significantly reduced macrosomia. Five reviews reported no significant differences in maternal outcomes such as GDM, gestational hypertension, preeclampsia, caesarean delivery, or induction of labor (Agha et al., 2014; Dodd et al., 2010; Du et al., 2018; Lau et al., 2017; Wu et al., 2022). The interventions had no effect on infant outcomes such as birthweight or gestational week of birth (Agha et al., 2014; Flynn et al., 2016; I-WIP, 2017; Lau et al., 2017).

Results highlighted mixed effectiveness of dietary and PA interventions. However, several reviews suggested that interventions combining healthy eating strategies with PA are more effective on weight management during pregnancy and postpartum for women with overweight or obesity.

3.4.4 Effectiveness of psychobehavioral interventions

Meta-analysis of 20 RCTs (n=7,956 women with overweight or obesity) found that motivational interviewing (MI) and/or cognitive behavior therapy (CBT) interventions had a significant effect on reducing GWG compared to control groups. In addition, 16 RCTs (n=4,336 women) evaluated the weight gain against GWG recommendations. Interventions reduced the proportion of women with excessive GWG (71% of intervention participants versus 77% of control participants) (Nightingale et al., 2023).

A review of five RCTs (n=971 women) reported that interventions that showed positive results in reducing GWG included a psychobehavioral component (e.g., self-monitoring, goal setting, and feedback) in addition to a combination of personalized diet and PA goals (Brown et al., 2012). In addition, Bernardo et al. (2024) reported that the behavioral and lifestyle counseling intervention yielded positive outcomes in managing weight during pregnancy, with the intervention group experiencing the gestational weight gain of less than 25.5% compared with the control group. Women in the intervention group also reported having significantly better scores for self-efficacy and self-image, as well as lower levels of depression (Brown et al., 2012). In a review of 18 trials (n= 2559 pregnant or postpartum women), nine trials reported a significant effect on PPWR in diet or diet and PA intervention groups compared to control groups. The effective interventions included goal setting and technology-based strategies (Dalrymple et al., 2018). Interventions using goal setting along with modifications to diet and PA were also effective in reducing GWG in the review of Flannery et al. (2019). On the contrary, the subgroup analysis of the review of Agha et al. (2014) found that there was no significant effect of behavioral interventions (regular feedback and/or motivational talks) on the reduced GWG in the intervention

groups compared to controls. However, behavioral interventions targeted at pregnant women with obesity had a significant effect on reduced GWG in the intervention group.

A recent review of 29 qualitative studies exploring women's perspectives of mHealth behavior change interventions revealed that self-monitoring was important when interventions aimed to enhance self-awareness, self-efficacy, or self-management. The goal-setting component of mHealth programs served as a motivational tool, enabling women to evaluate their individual needs and use the guidance and support provided by the intervention to achieve their goals. Peer support groups facilitated learning from the experiences, challenges, and successes of other women in similar situations. Essential design features of these interventions included peer-to-peer interaction, positive reinforcement, cultural inclusivity, and aesthetic appeal. The advantages of mHealth tools included time efficiency and the flexibility to engage in health behavior changes at any time and place (McGovern et al., 2024).

Several reviews suggested that interventions including psychobehavioral elements and support from healthcare professionals are more effective on weight management during the perinatal period. Technology was found to be a motivating tool or a self-monitoring tool as a part of intervention.

3.4.5 Interventions targeting behavior of maternity care professionals

One review of seven studies (n=335 participants) evaluated maternity care professionals' behavior in managing perinatal obesity and/or gestational weight gain. The results revealed the need for additional training and addressed specific knowledge deficits such as nutrition and exercise. Many intervention components have the potential to change professionals' behavior including motivational interviewing training, interfaces with electronic medical records, and implementation of maternal care pathways. A change in the pattern of gestational weight gain counseling such that counseling is consistent with the GWG recommendations was found. In addition, several barriers to communication were identified which included stigma that may be associated with obesity, making women feel uncomfortable, professionals feeling uncomfortable with their own weight, professionals feeling judgmental or overly negative, and professionals feeling they are limiting women's choices (Kominiarek et al., 2018).

These results suggest that education of maternity care professionals would be useful in avoiding stigma and maximizing the support of women with overweight in maternity care.

Table 1. Summary of meta-analysis.

Author(s), year	Review and comparison	Studies (N)	Outcome (units)	Effect estimate (95% CI)	Heterogeneity				*P*
					χ^2 (df)	*P*	T^2	I^2	
Agha et al., 2014	Behavioral interventions vs. standard maternity care (OB)	4	GWG (kg)	-4.65 (28.74–20.56) MD	40.80 (3)	<0.00001	15.61	93%	
	Behavioral interventions vs. standard maternity care (all BMI categories)	14	GWG (kg)	-1.66 (-3.12–−0.21) MD	94.76 (13)	<0.00001	6.08	86%	
Behnam et al., 2022	PA vs. control	8	GWG (kg)	−0.18 (−0.33–−0.02) SMD				59%	
	Diet vs control	3	GWG (kg)	−0.55 (−1.16–0.06) SMD				92%	
	Diet + PA vs control	12	GWG (kg)	−0.38 (−0.57–−0.20) SMD				89%	
	Subgroup: behavioral therapy vs control	5	GWG (kg)	−0.40 (−0.62–−0.18) SMD				79%	
	PA vs. control	5	Excessive GWG (kg)	0.67 (0.48–0.94) SMD				42%	
	Diet + PA vs control	7	Excessive GWG (kg)	0.48 (0.30–0.74) SMD				86%	
	Subgroup: behavioral therapy vs control	3	Excessive GWG (kg)	0.42 (0.21–0.85) SMD				75%	
Choi et al., 2013	PA interventions vs. comparison	2	GWG (kg)	-1.74 (-3.66–0.19) WMD	6.54 (6)	0.832	N/A	8.2%	0.077
	PA + diet intervention (supervised) vs comparison	3	GWG (kg)	-1.17 (-2.14–−0.21) WMD					0.017
	PA + diet intervention (unsupervised) vs comparison	3	GWG (kg)	0.44 (-1.86–2.74) WMD					0.707
	PA + diet intervention (supervised) vs comparison	1	PPWR (kg)	-1.50 (-1.98–−1.02) WMD	6.68 (5)	0.246	N/A	25.1%	0.000
	PA + diet intervention (unsupervised) vs comparison	3	PPWR (kg)	-0.94 (-2.00–0.12) WMD					0.082
Dodd et al., 2010	Dietary intervention vs. standard care	4	GWG (kg	-3.10 (-8.32–2.13) WMD*	40.19 (3)	<0.001	25.93	93%	0.25
Du et al., 2018	PA intervention vs standard care	12	GWG (kg)	-1.14 (−1.67–−0.62 MD	12.19 (11)	0.35	N/A	10%	<0.001
I-WIP, 2017	PA + diet intervention vs control (OW)	28	GWG (kg)	−0.75 (−1.22–−0.27)				39.8%	
	PA + diet intervention vs control (OB)	31	GWG (kg)	−0.85 (−1.41–−0.29)				39.8%	
Kuang et al., 2023	Exercise vs conrol	15	GWG (kg)	-0.20 (-0.31–−0.08)	55.36 (14)	<0.001	0.03	75%	0.0007

Lau et al., 2017	E-based intervention vs control	8	GWG (kg)	-0.63 kg (-1.07–−0.20)	7.00 (6)	0.32		14%	0.004
	E-based intervention vs control	2	PPWR (kg)	-3.29 (-8.41–1.82)	4.74 (1)	0.03		79%	0.21
Nightingale et al., 2023	MI-CBT intervention vs control (all BMI)	10	GWG (kg)	-0.22 (-0.35–−0.09) SMD		0.000		74.4%	0.037
	CBT intervention vs control (all BMI)	9	GWG (kg)	-0.14 (-0.26–−0.01) SMD		0.113		38.3%	0.008
	MI intervention vs control (all BMI)	1	GWG (kg)	-0.36 (-0.94–−0.22) SMD					0.337
	MI and/or CBT intervention vs control (OW)	14	GWG (kg)	-0.24 (-0.36–−0.13) SMD		0.005		56.4%	0.005
Shieh et al., 2018	PA and/or healthy eating intervention vs control	21	GWG (kg)	-1.81 (-3.47–−0.16) MD	1591.69 (20)	0.00001	13.74	99%	0.03
	Healthy eating intervention vs control	4	GWG (kg)	-5.77 (-9.34–−2.21) MD	98.87 (3)	0.00001	12.22	97%	0.002
	PA intervention vs control	6	GWG (kg)	-0.28 (-1.50–0.90) MD	2.33 (5)	0.80	0.00	0%	0.65
	PA + healthy eating intervention vs control	11	GWG (kg)	-0.82 (-1.28–−0.36) MD	29.27 (10)	0.001	0.31	66%	0.0005
Sui et al., 2012	PA intervention vs control	5	GWG (kg)	-0.36 (-0.64–−0.09 SMD	1.86 (4)	0.76		0%	0.008
*Wu et al, 2022	PA intervention vs control	2	GWG (kg)	-1.98 (-3,50–−0.47) MD					
	Diet vs control	4	GWG (kg)	-1.95 (-3.19–−0.71) MD					
	PA + diet vs control	10	GWG (kg)	-1.21 (-1.92–−0.50) MD					
Yeo et al., 2016	PA + diet intervention vs control (OW/OB)	32	GWG (kg)	-1.71 (-2.55–−0.86) WMD		0.001		83.08%	0.001
	PA + diet intervention vs control (OW)	9	GWG (kg)	-1.81 (-3.14–−0.48) WMD		0.13		36.14%	0.01
	PA + diet intervention vs control (OB)	20	GWG (kg)	-2.07 (-3.39–−0.75) WMD		0.001		83.66%	0.04
	PA + diet intervention vs control (prof. led)	7	GWG (kg)	-3.88 (-7.01–−0.75) WMD		<0.001		94.12%	0.02
*Yu et al., 2024	Diet		GWG (kg)	−1.27 (−2.23, −0.32) MD		0.521		0%	
	PA		GWG (kg)	−0.60 (−1.19, −0.00) MD					
	Behavior modification		GWG (kg)	−0.34 (−0.57, −0.10) MD					

BMI body mass index (calculated as weight in kilograms divided by height in meters squared), CBT: cognitive behavior therapy, GWG: gestational weight gain, MI: motivational interview, OB: obese, OW: overweight, PA: physical activity, PPWR: postpartum weight retention. *Network meta-analysis

Table 2. Summary of narrative reviews.

Author(s), year	N of studies	Main findings
Aung et al, 2022	21	Four major themes were identified: 1) Mixed findings of lifestyle interventions for weight management: Among the 18 studies focusing on lifestyle advice, seven demonstrated significant results. Intervention groups receiving extensive additional care, including motivational talks from a midwife and dedicated discussions on enablers and obstacles recorded in logbooks at each follow-up visit, exhibited significantly lower GWG and overall weight gain compared to controls. 2) Ineffectiveness of probiotics or metformin for weight management: Two intervention strategies that incorporated medications alongside lifestyle interventions did not yield significant results. 3) Mixed findings of psycho-behavioral interventions in weight management: Three studies incorporating psycho-behavioral components, such as emphasizing self-efficacy through regular self-monitoring, text messages, social support via Facebook groups, telephone counseling sessions, and motivational interviewing, showed significant results. 4) Midwifery role as an integral component in multidisciplinary interventions for weight management: Six out of seven studies with extensive midwifery input and continuity of care reported successful outcomes. Midwives play a crucial role in multidisciplinary interventions for weight management. Behavioral interventions involving motivational interviewing delivered by the same midwife can significantly limit GWG for women who are overweight or obese.
Bernardo et al., 2024	6	Dietary counseling and PA interventions showed no significant effect on quality of life when compared with that under standard prenatal care. Greater adherence to the protocol was associated with better post-intervention physical quality of life. PA interventions showed no differences between the groups, but behavioral and lifestyle counseling intervention showed positive results in weight control throughout pregnancy, with the experimental group achieving a gestational weight gain of percentage of <25.5% compared with the control group. Greater gestational weight gain was also associated with worsening mood, depressive symptoms and lower physical health-related quality of life during pregnancy.
Brown et al, 2012	5	Three studies reported significantly lower GWG in the intervention group compared to the control group for normal weight, overweight and obese women. Two studies found that weight retention was significantly lower in the intervention group at 6 months postpartum. Women in the intervention group had significantly better scores for self-efficacy. In addition, scores for self-image increased, while lower levels of depression were noted in the intervention group when compared with the control group.
Dalrymple et al, 2018	18	Of the 18 studies, nine reported a significant effect on PPWR when compared to controls. Of these nine effective trials, one focused on a diet-only approach and eight focused on diet and PA. For the effective interventions, dietary strategies incorporated individualized weight loss goals and healthy eating with nutritional counselling. Successful interventions included technology-based strategies in three trials or both face-to-face and technology-based approaches in eight trials. Four trials (pregnancy only n = 2, pregnancy and postpartum n = 2) reported on significant associations between GWG and PPWR; two studies reported a positive association between GWG and PPWR. Two studies reported an association between appropriate GWG within the IOM guidelines and lower PPWR.
Flannery et al, 2019	4	The intervention group exhibited significant reductions in the incidence of GDM, GWG, and the number of newborns with a birth weight exceeding 4000 g compared to the control group. Across the 19 intervention studies, a total of 19 different BCTs were applied, with each study incorporating between 1 and 10 BCTs. The most frequently described BCTs were 'self-monitoring of behavior' and 'instruction on how to perform the behavior,' identified in 13 out of the 19 studies (76.5%). 'Information about health consequences' was utilized in 8 out of the 19 interventions (47.1%), while 'social support (unspecified)' was employed in 7 out of the 17 interventions (41.2%), averaging 11.1 instances per intervention. In one comparator group, 'social support (unspecified)' and 'instruction on how to perform the behavior' were included in weekly sessions of relaxation, respiratory exercises, light stretching, and focus group discussions on maternity.

Flynn et al, 2016	13	Three studies reported a significant reduction in GWG in the diet-only intervention group compared to the control group, with no significant differences observed in infant birth weight. Ten studies employed combined interventions targeting both dietary intake and PA. Of these, six studies reported a significant decrease in GWG in the intervention group, while four found no difference in weight gain. Several studies noted improvements in maternal diet following the intervention, indicating that pregnant women with overweight and obesity are receptive to dietary changes in response to an intervention.
Kominiarek et al, 2018	7	Motivational interviewing themes or skills were common components of the professional's education and training. One study evaluated the efficacy of motivational interviewing training in a pre-post study design, whereas two other studies incorporated motivational interviewing in the training but did not evaluate professionals' change in these skills. Other common themes among the studies were professionals lack of knowledge and confidence in either the management of perinatal obesity or gestational weight gain and communication issues (e.g., providers couldn't "find the words" to discuss these sensitive topics). The evaluations of the interventions were mostly positive containing comments such as "feasible to deliver", "changed practice", "gained more confidence", and "improved knowledge". There are many intervention components that have the potential to change provider behavior including interfaces with the electronic medical records, training in motivational interviewing and implementation of maternal care pathways or treatment algorithms.
Lamminpää et al, 2018		A total of 10 studies reported significant differences between the study and the control groups in limiting the GWG (n = 10) and/or preventing GDM (n = 3), of which seven focused on GWG, and three focused on both. Five studies reported no significant differences between the intervention and the control groups. The similarities among the effective interventions were a combination of a dietary component and a certain extent of PA. The interventions mainly delivered by a midwife, or a lifestyle/ health coach had impacts on the outcomes. The roles of midwives or nurses in the interventions were highlighted in only four studies, in which each was reported as effective.
McGovern et al., 2024	29	A total of 15 studies had specific mHealth interventions comprising online webinars, smartphone applications, telemedicine, and health behavior change coaching. Two themes were generated from the meta-synthesis: mHealth as a supportive tool, and mHealth as a personalized tool. The first theme had four sub-themes: monitoring, motivation, information trustworthiness, and peer support. The second theme had three sub-themes: program design, technology challenges, and convenience/flexibility. Based on results recommendations were made, such as: 1) Building in self-monitoring is important if targeting self-awareness, self-efficacy, and self-management. 2) Goal setting, personalized risk awareness, tailored problem-solving and peer interactions all support the development of motivation for health behavior change in mHealth tools and should be considered in their development. 3) Deliver and promote the interventions with recognized and trusted sources, for example, healthcare professionals, or co-design with representative groups of women. 4) Integrating peer support is important to building engagement with mHealth tools. 5) Key design features were peer-to-peer interactivity and positive reinforcement, culturally inclusive and esthetically pleasing.

BCT: behavior change technique, GDM: gestational diabetes mellitus, GWG: gestational weight gain, IOM: the Institute of Medicine, PA: physical activity, PPWR: postpartum weight retention

3.5 Knowledge gaps in current literature

Even though a multiplicity of perinatal weight management interventions for women with overweight exist, some gaps still require further investigation.

First, the results of perinatal weight management interventions for women with overweight or obesity are heterogeneous and contradictory. This variability may be attributed to differences in study designs, intervention types, durations, and outcome measures. This inconsistency underscores the need for a comprehensive development, implementation, and evaluation of the intervention to identify the most effective strategies and understand the context in which they are most beneficial.

Second, the majority of intervention studies lacked a theoretical framework. Most of the weight management interventions focused on PA and diet, which are important and essential components of weight management. In recent years, behavioral interventions have increased and have mostly demonstrated a significant reduction in excessive GWG among women with overweight (Aung et al., 2022; Behnam et al., 2022; Bernardo et al., 2024; Brown et al., 2012; Choi et al., 2013). Although perinatal weight management studies have recently included behavioral components in their interventions, only a few have based their weight management intervention on a theory (Aung et al., 2022; Behnam et al., 2022; Flannery et al., 2019; Lau et al., 2017). Given that weight management for women with overweight can be stigmatizing and challenging, it is crucial for interventions to incorporate psychobehavioral elements to necessitate behavior change. As a result, there is a need to find methods that support women's behavior change and thus, effective perinatal weight management interventions should be grounded in behavior change theories that serve as a framework for both development and implementation.

Third, in most studies, the role of maternity care professionals in weight management interventions has been minor, with a primary focus on pregnant women's lifestyle modifications. There is a significant gap in the research regarding how maternity care professionals implement weight management guidelines and provide counseling on these issues. These factors are essential in motivating women and ensuring successful outcomes. Improving the effectiveness of existing maternity care, particularly in the realm of weight management, is crucial. This enhancement has the potential to significantly influence women's behavior and overall weight management during the perinatal period. By integrating tailored weight management strategies and behavior change techniques into routine maternity care, professionals can better support women in achieving and maintaining a healthy weight, ultimately leading to improved maternal and fetal outcomes.

Finally, long-term, continuous monitoring of pregnant or postpartum women's health parameters was not reported in the reviews. Interventions that include both diet and PA components and contain individualized support and self-monitoring are more likely to be successful in weight management. Utilizing technology as a part

of interventions delivery (email, telephone, text messaging, internet) is practical and motivating in addition to face-to-face contact. There is still a need to evaluate continuous monitoring of women's health parameters during the perinatal period, which could provide unique and representative data on the levels and changes of health parameters or health outcomes. Personalized monitoring could increase women's awareness of their health, and it could be utilized as part of maternity care.

The complexity of the interventions and the reporting of the implementation process were overlooked in the existing studies. The feasibility of incorporation into clinical settings and strategies to improve the adherence of interventions needs broader research. The weight management of women with overweight and obesity during the perinatal period is a complex phenomenon and has a strong psychosocial aspect. This requires investigation using a holistic approach and multifaceted methods. In addition, prospective research with extended and continuous follow-up periods is imperative to enhance our understanding of the health trajectory and weight management strategies in women with overweight during the perinatal period. Objective and continuous measurements are needed to reach an understanding of women's health parameters and utilize them in weight management interventions, which should be systematically designed and evaluated. Maternity care professionals and pregnant or postpartum women's involvement in the interventions development process is essential to gain a full understanding of the phenomenon and to support women with overweight in the future.

4 Aims of the Study

The overall aim of this study was to develop and evaluate the feasibility of a Wearable Internet-of-Things-based weight management intervention for women with overweight or obesity during pregnancy and the postpartum period. The study was carried out in two phases: (1) development of the intervention; and (2) feasibility of the intervention.

Phase 1: Development of the intervention

Two substudies were conducted as part of phase 1. The aims of substudy I were to: (1) identify and describe weight management behaviors of women with overweight during pregnancy and the postpartum period to discover the target behaviors of weight management intervention; (2) develop an evidence-based weight management intervention; and (3) choose appropriate implementation strategies to be used in maternity care.

Detailed research questions:

1. What are the target behaviors for weight management that need to change from the perspectives of pregnant women with overweight and maternity care professionals? *(Original publication I)*
2. What are the relevant functions that weight management interventions should serve in the local context for women with overweight during the perinatal period? *(Summary)*
3. What are the core components of weight management interventions from the perspectives of pregnant women with overweight and maternity care professionals*? (Original publication III, summary)*
4. What are effective implementation strategies of weight management intervention for promoting healthy weight during the perinatal period in maternity care? *(Original publication III, summary)*

5. How usable are the wearable devices during pregnancy and the postpartum period from the perspectives of pregnant women with overweight and maternity care professionals? *(Summary)*

The aim of substudy II was to evaluate the feasibility of the WIoT technology in continuous monitoring of maternity care.

Detailed research question:

6. How can WIoT technology be utilized for continuous monitoring of health parameters during pregnancy and the postpartum period in maternity care? *(Original publication II, summary)*

Phase 2: Feasibility of the intervention

Phase 2 included one substudy. The aim was to assess the preliminary effectiveness of the weight management intervention in terms of improving self-efficacy in eating and PA and preventing excessive GWG. In addition, the aim was to assess the feasibility of implementation outcomes.

Detailed research questions:

7. What is the effectiveness of the weight management intervention in terms of improving self-efficacy in eating and PA and preventing excessive gestational weight gain? *(Original publication IV)*
8. What is the perceived feasibility, in terms of fidelity, acceptability and adherence, of implementing weight management intervention in maternity care settings among pregnant women with overweight and maternity care professionals? *(Original publication IV, summary)*

5 Materials and Methods

5.1 Methodological framework

In this study, the MRC framework for developing and evaluating complex interventions (Skivington et al., 2021) was used as the methodological framework. The framework consists of four phases: developing or identifying a complex intervention, feasibility, evaluation, and implementation. This study focuses on the first two phases of the framework: development and feasibility **(Figure 3).** a cocreation approach was utilized during the intervention development phase, which included identifying the end users' perspectives and evidence base of the weight management interventions (substudy I) and assessing the feasibility of the health technology as a component of intervention (study II) (Leask et al., 2019). The feasibility phase included assessing the preliminary effectiveness of the intervention and the feasibility of the intervention (study III). The detailed aims and research questions were described above, and the overall study design is presented in **Figure 4**.

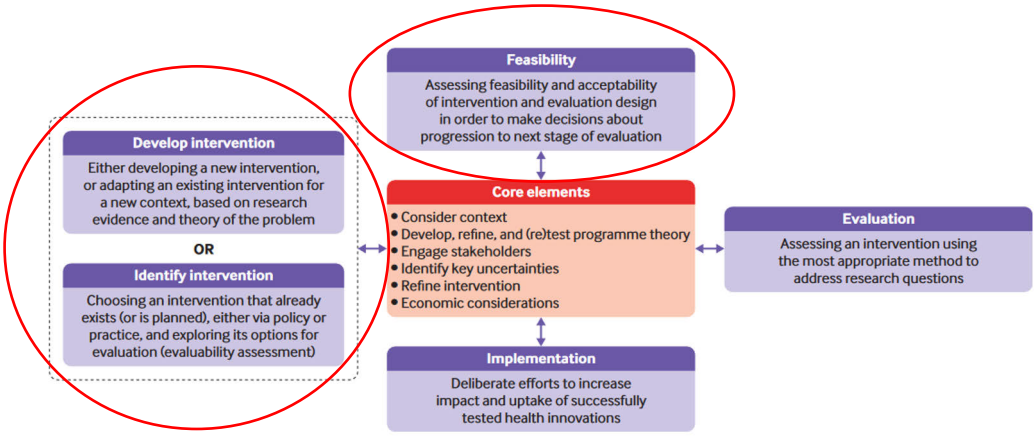
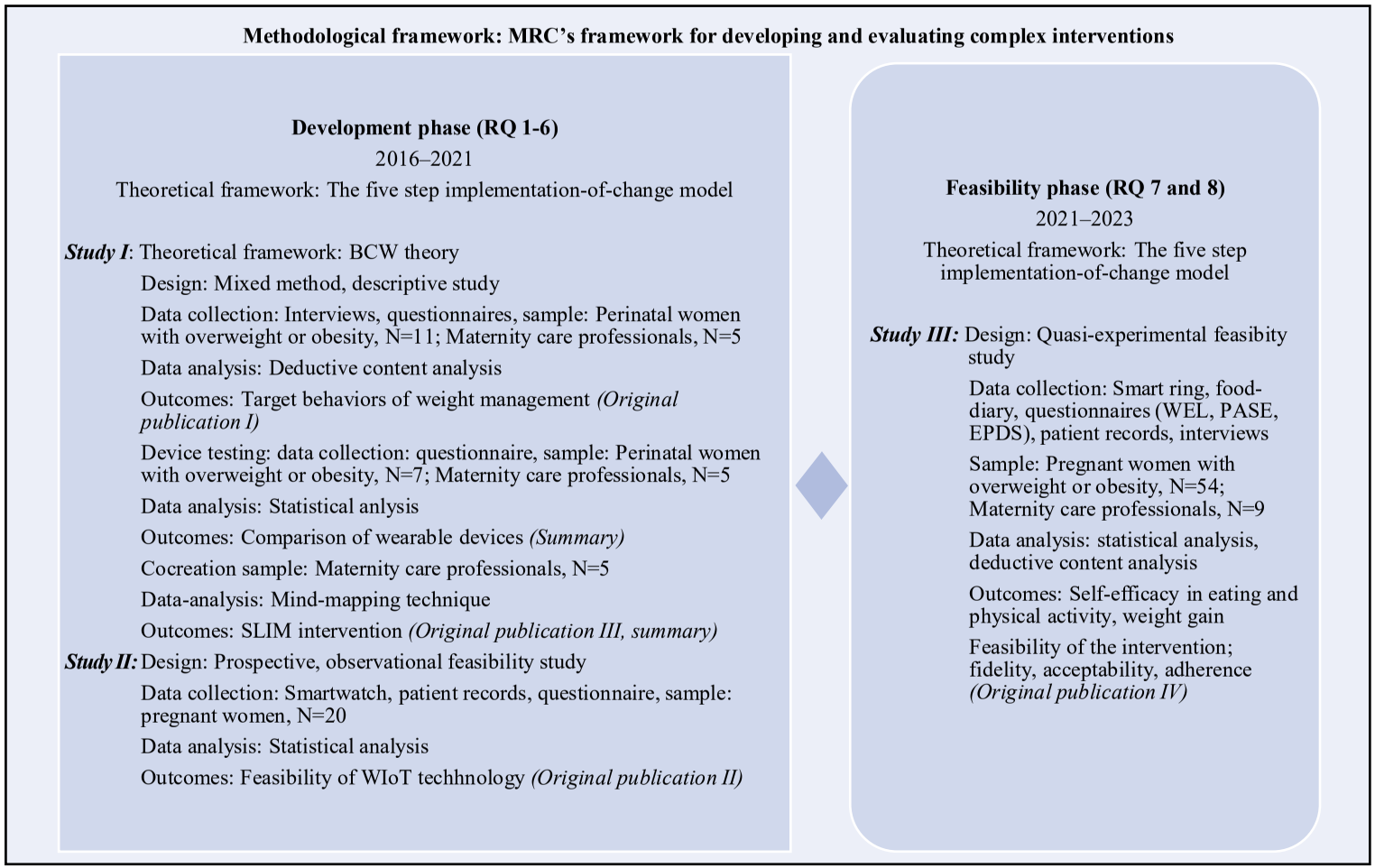


Figure 3. Framework for developing and evaluating complex interventions according to Skivington et al. (2021) (Reproduced with permission of the copyrights holder).



MRC: Medical research council, RQ: research question, WEL: Weight efficacy lifestyle PASE: Physical activity self-efficacy, EPDS: Edinburg postnatal depression scale

Figure 4. The overall study design.

5.2 Study design

The five-step implementation-of-change model (Grol et al., 2013) guided the development process of the weight management intervention (**Figure 5**). The first step was to evaluate existing evidence of previous weight management interventions (described in review of the literature-chapter 3). Existing literature on weight management interventions during pregnancy highlighted the persistent need for strategies that enhance the engagement of women with overweight with a healthy lifestyle and the active involvement of participants in the intervention design process. The intervention was developed in collaboration with pregnant women with overweight and PHNs working in select maternity clinics with a cocreation approach.

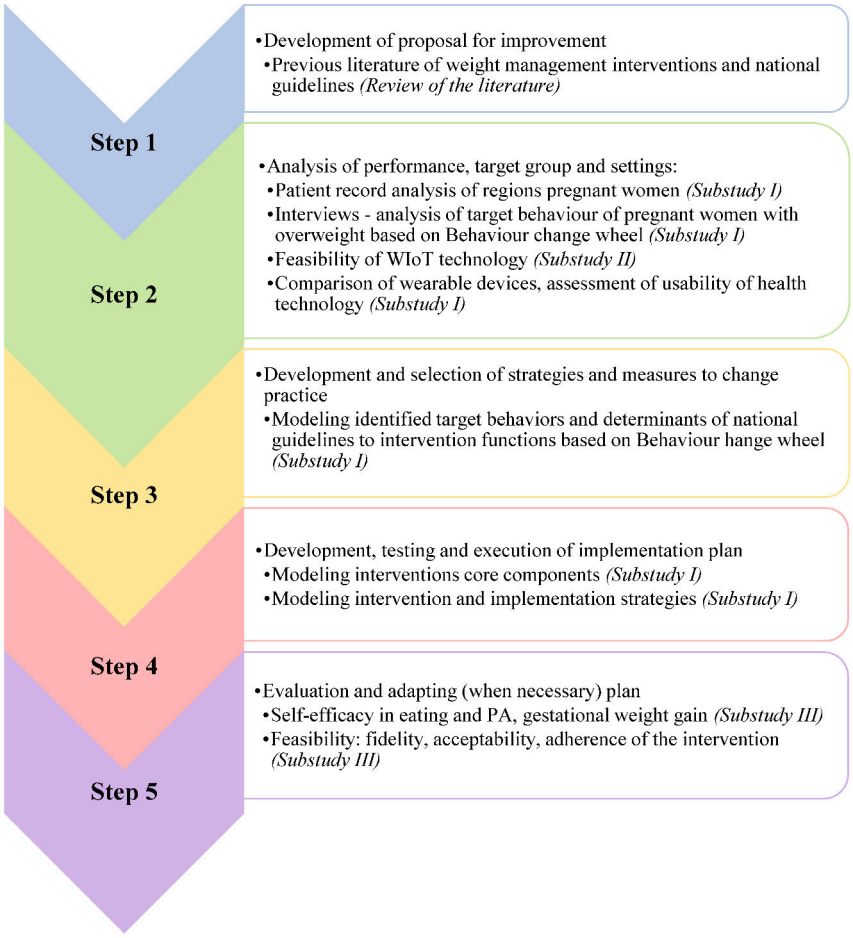


Figure 5. The process of development and feasibility of the weight management intervention.

5.3 Development phase

5.3.1 Study design and participants

Substudy I: Development of a weight management intervention for overweight pregnant women using Behaviour Change Wheel (BCW) - Analysis of performance, target group, and settings (Step 2)

Perceptions of weight management support among overweight pregnant and postpartum women were investigated using a qualitative, descriptive study design. To justify the importance of the subject and to encourage maternity care professionals' interest, a patient record analysis of pregnant women in selected areas was conducted, and the data were presented in a meeting at maternity clinics with PHNs and their Nursing Director in January 2019. Discussion with PHNs revealed that they had recognized the problem of obesity and were willing to cooperate with researchers and start developing interventions for women with overweight to be utilized in maternity care. The patient record data of two municipalities in 2018 showed that over half (67.9%) of 84 pregnant women were overweight or obese. Characteristics of overweight pregnant women are presented in **Table 3.** Descriptive statistics of perinatal outcomes of pregnant women with overweight

Table 3. Descriptive statistics of perinatal outcomes of pregnant women with overweight.

Characteristics	Pregnant women with overweight or obesity in year 2018 (n=57)
BMI* (kg/m²)	
25.0–29.9	30 (52.6%)
30.0– or more	21 (36.8%)
Missing value	6 (10.5%)
Gestational diabetes, n (%)	24 (42.1%)
Means of delivery, n (%)	
Vaginal	44 (77.2%)
Vacuum assisted	3 (5.3%)
Cesarean section	10 (17.6%)
LGA, n (%)	4 (12.3%)
Child in NICU, n (%)	7 (12.3%)
EPDS score ≥ 10, n (%)	2 (3.5%)
Missing value	27 (47.4%)

*BMI: Body Mass Index

A researcher contacted all PHNs (n=8), who were working at two maternity clinics in four municipalities in the rural area of the Hospital District of Southwest Finland, via email. The maternity clinics were chosen with convenience sample. Five (n=5) PHNs participated in the study. Three PHNs worked in a maternity and child health clinic and two of them worked in the maternity clinic. The PHNs' experience ranged between 2 and 22 years. Women with overweight (n=11) were recruited with a purposive sample: the public health nurses informed the eligible women about the study, and then the researcher contacted the potential participants. Three (n=3) women were overweight and eight (n=8) were obese. Eight (n =8) women were interviewed between gestational weeks 18–33 and three (n=3) women were interviewed during the immediate postpartum period 11–20 weeks after the birth (Saarikko et al., 2021, original publication I).

5.3.2 Data collection

Researchers (JS, HN-V and AA) developed a semistructured interview guide for both women with overweight and public health nurses. The BCW theory guided the themes of the interview guides, which contained questions about weight management support, barriers, and facilitators of delivering the weight management intervention and utilizing technology in weight management support. The data were collected using individual and focus group interviews between April 2019 and January 2020. Two focus group interviews with PHNs were conducted by researchers JS and HN-V, and eleven individual interviews with pregnant or postpartum women were conducted by the primary investigator (JS). Maternal background characteristics (age, BMI, marital status, education, employment status) were collected with a questionnaire. All interviews were audio-recorded, and field notes were also made (Saarikko et al., 2021, original publication I).

After the interviews, the participants were asked to test two wearable devices. Eleven women with overweight and eight PHNs were asked to test the devices, Oura smart ring and Samsung Gear Sport watch, for seven consecutive days and fill in a semistructured diary for each day. Oura is a smart ring that monitors functions including HR, HR variability, steps, body temperature, and sleep (Oura 2022). Samsung Gear Sport is a water-resistant smart watch (44.6 x 42.9 x 11.6mm) that monitors functions including steps, HR, and sleep. The smart watch has an accelerometer, barometer, gyro sensor, heart rate sensor, and light sensor (Samsung 2020). Both wearable devices needed to be synchronized to applications compatible with Android and iOS mobile devices. After the follow-up period the user experiences were collected with questionnaires that included questions about the subject's estimate on a scale from 1 to 5: (1) How easy it was to use the device (1 = very difficult and 5 = very easy); (2) How comfortable the device was to use (1 =

very uncomfortable, 5 = very comfortable); and (3) How easy the related application was to use (1 = very difficult, 5 = very easy), and an open question for any other comments.

Substudy II: A feasibility study of continuous monitoring of health parameters during pregnancy and the postpartum period (Step 2)

A prospective observational study was conducted to examine the feasibility of the WIoT technology to monitor the health parameters (PA, sleep, and HR) continuously during pregnancy and the postpartum period. Data were collected in two maternity outpatient clinics in southern Finland between 2016 and 2017 using a convenience sample of (n=20) nulliparous pregnant women. The midwives working at the maternity outpatient clinics informed the eligible women about the study, and then the researchers contacted potential participants. Inclusion criteria were women expecting their first child, ≥18 years of age, and ≤15 of weeks of singleton gestation. Women were excluded if they did not understand Finnish or English or did not have a PC, tablet, or mobile device with which to synchronize data.

Maternal background characteristics, such as age, BMI, marital status, educational background, employment status, smoking habits, and prepregnancy PA were gathered through a questionnaire. Data on pregnancy and delivery were collected from the maternity card and patient records. Health parameters were collected objectively with WIoT technology throughout pregnancy and the postpartum period. To collect health parameters from the participants, Garmin vivosmart, a smart wristband (21 mm x 12.3mm, 29.6g) was used (Garmin, 2017). The collected data were transmitted to cloud servers via a smartphone or a personal computer. The data were stored and preprocessed in the cloud. Heart rate values were homogenized by interpolating or averaging them, and sleep and step count data were obtained from the Garmin (Saarikko et al., 2020, original publication II).

5.3.3 Data analysis

Qualitative analysis, substudy I

In substudy I, the data were organized into a systematically structured format using deductive content analysis. The data were coded using a deductive framework (Gale et al., 2013), which integrates the components of the COM-B model and the Theoretical Domains Framework (TDF). Responses were grouped into capability, opportunity, and motivation categories and included links to the TDF domains within the text, consistent with the COM-B model (Michie et al., 2014) by primary researcher (JS). The initial themes were further refined based on constructive

criticism and feedback provided by research team members (HN-V & AA). The themes were labeled with expressions that embodied the participants' descriptions after a consensus (Saarikko et al., 2021, original publication I).

Data on weight management behaviors in terms of the COM-B -model (Saarikko et al., 2021, original publication I) were used to model a weight management intervention and implementation strategies advocated by the BCW (Michie et al., 2011). This encompassed a comprehensive range of intervention functions, namely Education, Persuasion, Incentivization, Coercion, Training, Enablement, Modeling, Environmental Restructuring, and Restrictions. These functions were considered alongside the foundational elements of the COM-B model and the TDF domains, ensuring a holistic approach to the categorization and interpretation of the data.

Additionally, a cocreation approach was included in the intervention development process (Leask et al., 2019). The template was used to analyze the dataset derived from the first round of workshops, as well as the diaries maintained during device testing. Intervention, content, and implementation options were identified by describing the development of the SLIM intervention using the COM-B model, TDF domains, BCW functions, and the BCT-Taxonomy (v1) utilizing the information from target behaviors (Saarikko et al., 2021, original publication I) and device testing. Intervention functions and BCTs mentioned within the interviews were individually identified and selected for the development of an intervention by one researcher (JS).

This analysis involved the mapping of identified intervention functions to their corresponding BCTs and facilitating a structured approach to data interpretation (Michie et al., 2014). For the analysis of data that did not conform to the coding framework, a mind-mapping technique was employed (Burgess-Allen & Owen-Smith, 2010). This technique facilitated the exploration of themes and patterns beyond the predefined categories. The initial analysis was executed by one researcher (JS). The research team members (HN-V & AA) convened and compared the analysis to avoid researcher bias.

Statistical analysis, substudies I and II

In substudy I, to describe women's background information, medians with ranges as continuous variables and counts with proportions for categorical variables were used. Descriptive statistics were used with the data collected from patient record analysis and device testing. Frequencies, percentages, means, and standard deviations (SD) were used when applicable to characterize the patient record data and feedback on the wearable devices. The analyses were performed with IBM SPSS Statistics, version 27 for Windows (Saarikko et al., 2021, original publication I).

In substudy II, women's background information and health parameters (PA, sleep, and HR data), means, SD, or CI and medians with ranges were described as continuous variables and counts with proportions for categorical variables. The changes in weekly step counts and sleep minutes were assessed during pregnancy as well as differences in average daily step counts and sleep, between pregnancy trimesters, with a linear mixed model with repeated measures, including one within factor (time = gestational weeks). A compound symmetry covariance structure was used for time. To analyze changes across trimesters in moderate to vigorous physical activity (MVPA) minutes, the Friedman test was used. Spearman correlation testing was used to explore associations between mean daily step count as well as mean daily sleep minutes during the trimesters and postpartum period. All tests were performed as two-sided tests with a significance level set at .05. The analyses in substudies I and II were performed using SAS System, version 9.4 for Windows (SAS Institute) (Saarikko et al., 2020, original publication II).

5.3.4 Development of the SLIM intervention

The SLIM intervention was developed with a cocreation approach (Leask et al., 2019) advocated by the BCW theory (Michie et al., 2014). In the process of developing the intervention's framework, two cocreation groups were convened to achieve a consensus. The cocreation groups consisted of two to three PHNs and a researcher (JS). The cocreation sessions included deliberations on pertinent intervention functions and the associated BCTs. The objective was to integrate diverse perspectives to inform the intervention design, ensuring that the intervention is both evidence-based and contextually relevant. The BCW guide recommends that intervention functions and policy categories should be assessed through the use of the APEASE criteria (affordability, practicality, effectiveness and cost-effectiveness, acceptability, side-effects and safety, equity)(Michie et al., 2014). In this study, because of the resource availability, the relevance of APEASE criteria was highlighted but not applied (Michie et al., 2011, 2014).

In the second phase of the cocreation process, a consensus was reached on the core components of the intervention. Furthermore, the development of the multifaceted implementation strategies was guided by the Expert Recommendations for Implementing Change (ERIC) model (Powell et al., 2015). The formulation of strategies was underpinned by the BCW framework, with particular emphasis on the inner setting and process of implementation domains of the Consolidated Framework for Implementation Research (CFIR) (Waltz et al., 2019). Between April and December 2020, a total of four cocreation workshops were conducted. These workshops were integral to the research methodology and each group involved two

to three PHNs and a researcher (**Figure 6**). Each workshop lasted approximately 90 minutes.

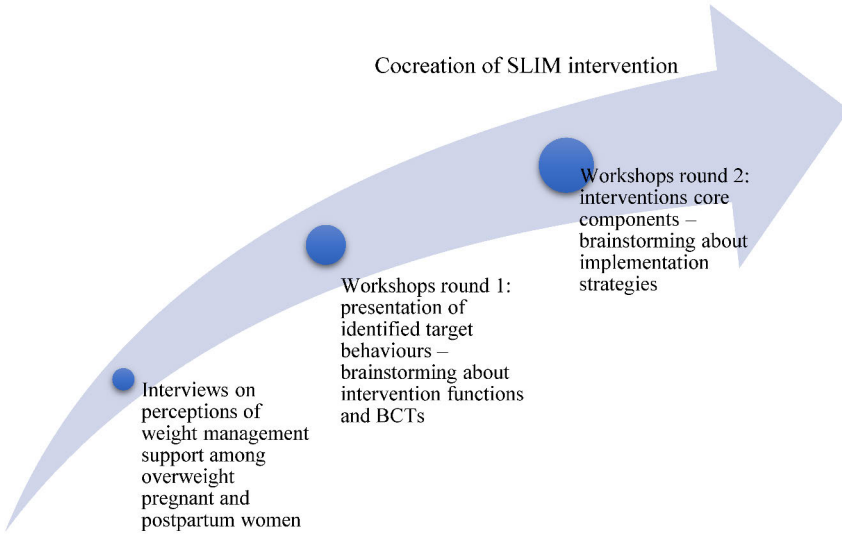


Figure 6. Cocreation development of the intervention.

5.3.5 The SLIM intervention

The TiDieR (Template for Intervention Description and Replication) framework was used to report the SLIM intervention (Hoffmann et al., 2014).

Brief name

The SLIM intervention was developed as part of the SLIM (Supporting Lifestyle Change in Obese Pregnant Women through Wearable Internet-of-Things) project.

Why

The intervention was developed in response to the escalating issue of maternal overweight and obesity which has become a global health concern (Ng et al., 2014). In Finland in 2019, over 40% of pregnant women were overweight and 17.6 % were obese (THL, 2021). Maternal overweight increases the risks of obstetric complications and newborn mortality and morbidity such as gestational diabetes, caesarean sections, preterm birth, and asphyxia-related complications at birth (European Perinatal Health Report, 2018; Persson et al., 2014). Previous research reported that weight management interventions reduce weight gain during pregnancy

(I-WIP, 2017); however, the gap between research evidence and practice in maternity care still exists. The implementation of weight management interventions is challenging for several reasons; for instance, broaching the subject of obesity with expectant mothers can be a sensitive issue, and the interventions may not yield immediate, significant effects. Rather than concentrating solely on weight reduction, the emphasis should be on fostering health promotion for women who are overweight and enhancing their self-efficacy in order to implement interventions effectively. In addition, previous interventions have not been implemented as part of maternity care. The customization of implementation strategies to the local context is imperative for bridging the existing gap between implementation research and the actual practice within clinical settings (Pfadenhauer et al., 2017; Waters et al., 2011).

What?

The SLIM intervention was designed for pregnant women with overweight, aiming to enhance their self-efficacy in weight management. PHNs in maternity clinics provided support to promote the welfare and health of these women. This support included guidance on circadian rhythm, PA, and nutrition as well as recommendations on diet and exercise during pregnancy and the postpartum period (Hakulinen et al., 2023). PHNs also offered advice on weight management and provided weight gain recommendations based on prepregnancy BMI to encourage women to adopt healthier behaviors for themselves and their unborn children, following evidence-based clinical practice guidelines in Finland (Lihavuus: Käypä hoito-suositus, 2024). The core components of the intervention included *health technology, motivational interviewing, feedback, and goal setting* (**Figure 7**).

Health technology utilized in the intervention included the Oura smart ring and the electronic food diary, FatSecret. Participants wore the smart rings continuously from gestational week 15 or earlier until the postnatal visit 12 weeks after birth. Additionally, participants completed a food diary for one week at three time points: at recruitment, gestational week 34, and eight weeks postpartum. Established maternity care support and guidance were integrated with health technology during routine visits. PHNs used the data collected with the smart ring and food diary to evaluate sleep, and nutrition during these visits. PHNs provided feedback based on the data and employed motivational interviewing to help individuals identify and resolve ambivalence about behavior change (Elwyn et al., 2014). Motivational interviewing is particularly useful in situations requiring behavior change where individuals feel uncertain because it focuses on resolving ambivalence (Mulherin et al., 2013). During perinatal visits, overweight women collaborated with PHNs to set goals, which were documented in patient records and reviewed in subsequent visits.

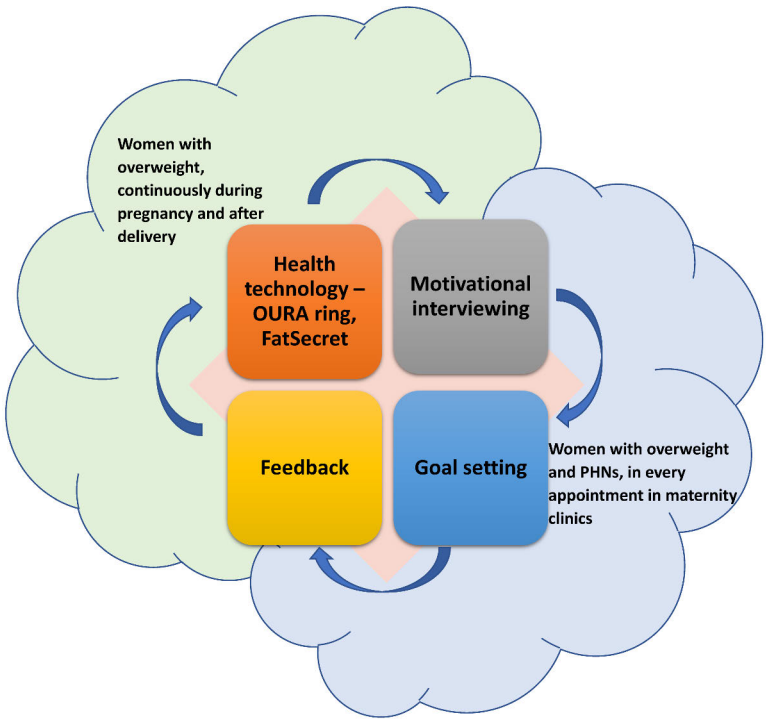


Figure 7. The SLIM intervention.

Who provides and how?

PHNs provide the intervention to pregnant women with overweight. In the first antenatal visit, the PHN introduces the SLIM intervention and asks permission for a researcher to contact the woman. Second, the researcher meets the participant and gives her a smart ring and instructions for the intervention after written informed consent. Continuous monitoring of health parameters lasts until 12 weeks after birth. PHNs utilize the data from the applications as part of weight management counseling.

Where, when, and how much?

The intervention is conducted in maternity clinic reception rooms during routine perinatal visits. After recruitment, participants start wearing smart rings continuously until 12 weeks after birth. At every antenatal visit, PHNs check the data in the participant's PC or mobile device to evaluate the health data (for example, PA,

sleep, and nutrition). The PHNs give feedback using motivational interviewing and create goals in collaboration with the participants and document it in their patient records. A researcher visits the maternity clinics every six months.

Tailoring

The intervention is conducted in a similar manner with every participant. Goals are created individually based on each woman´s capability, opportunity, and motivation.

Modifications

Usability and fidelity of the intervention is evaluated in educational meetings with PHNs, and modifications are discussed, when necessary.

How effective

The feasibility, in terms of fidelity, acceptability, and adherence to the intervention, is assessed during and after the follow-up period from the perspectives of PHNs and women with overweight. The PHNs perspectives are evaluated with educational meetings, exit interviews, and the self-administered logbooks they complete during routine perinatal visits, and the perspectives of women with overweight are evaluated with the use of the health technology and exit interviews.

Implementation strategies

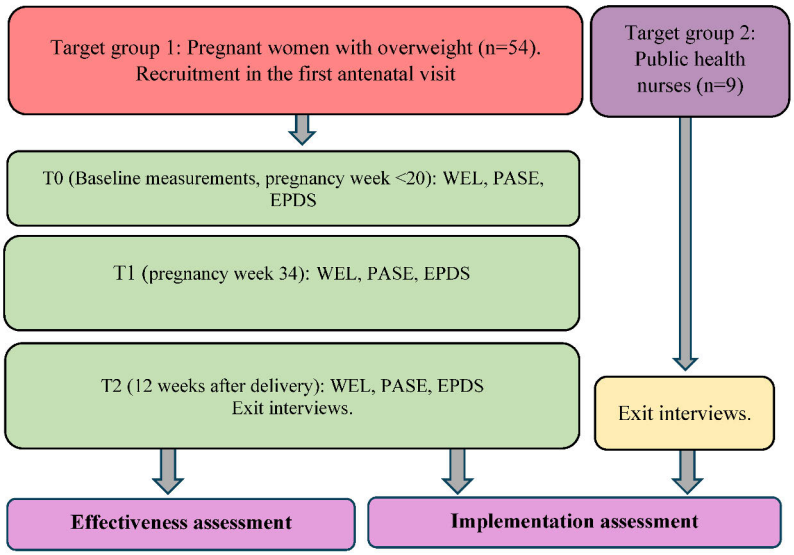
Educational meetings involved one-hour sessions during scheduled appointments with PHNs and were delivered by the researcher (JS). Educational meetings occurred every six months during the follow-up period. In addition, *educational materials* developed by the researcher were delivered during meetings. *The local opinion leaders*, who were selected among the PHNs, fulfilled an important role in liaising other nurses delivering the intervention and influencing their participation. *Mandate change,* to convince the Nurse Directors about the importance of, and to have their support for the intervention, was conducted via face-to-face meeting at the beginning and afterword via email. To promote adherence to the intervention, nurses were encouraged to contact researchers if any issues occurred relating to the implementation of the intervention.

5.4 Feasibility phase

5.4.1 Study design and participants

Substudy III

A prospective, nonrandomized, quasi-experimental (pre-post) intervention trial was conducted in three public maternity clinics located in five municipalities in the Hospital District of Southwest Finland between 2021 and 2023 (Clinicaltrials.gov ID: NCT04826861). The feasibility study focused on assessing the effectiveness of the SLIM intervention in terms of improving self-efficacy in eating and PA and preventing excessive gestational weight gain of women with overweight during pregnancy and the postpartum period. A detailed description of the study procedures is presented in **Figure 8**.



WEL: weight efficacy lifestyle questionnaire, PASE: Physical activity self-efficacy scale, EPDS: Edinburgh Postnatal Depression Scale

Figure 8. The design of substudy III.

In the developmental phase of the intervention (substudy I), two maternity clinics, along with the PHNs working there, were recruited as part of the cocreation process. To generate a more comprehensive perception of the feasibility of the SLIM intervention, one more public maternity clinic was recruited. Approvals from the

Nursing Directors of the health centers were obtained. All PHNs (n=9) working in select maternity clinics (n=3) were eligible to participate in the study.
PHNs recruited women with overweight during their first antenatal visit using convenience sampling. The sample size was determined using power calculation. The power analysis was calculated based on two scales: self-efficacy in eating as measured by the weight efficacy lifestyle (WEL) questionnaire (Clark et al., 1991) and physical activity self-efficacy (PASE)(Marcus et al., 1992). Due to the limited initial data, the statistical analysis was conducted using one-sided t-tests to evaluate the difference between two dependent means with an effect size of 0.50, a power level of 0.80, and a significance level of 0.05. Calculations included a 20% loss. The calculations, based on both scales, revealed that a sample of 54 pregnant women with overweight was needed to detect the difference in changes to eating self-efficacy or PA self-efficacy (Saarikko et al., 2023, original publication III).

At the first antenatal visit, the PHNs provided a letter of information and asked permission for the researchers to contact the potential participants. The researchers then explained the study purpose and procedures to the women in a scheduled appointment. In addition, a smart ring and guidelines detailing the procedural steps for downloading and utilizing the requisite applications were provided by the researcher. The participants were instructed to download specific applications—Oura, FatSecret, and SLIM—onto their personal mobile devices. For the purpose of the study, unique emails, usernames, and passwords were generated, which the participants used to create their accounts with these applications. Altogether n=272 women were assessed for eligibility, of which n=217 were excluded. The refusal rate was at least 53% (calculated with two maternity clinics and a BMI level of 27 or more). One (n=1) participant was not reached after recruitment, and four (n=4) participants had a miscarriage during early pregnancy. Four (n=4) participants dropped out during pregnancy because of health reasons such as psychosocial issues, and one (n=1) after the birth**.** The flowchart of the participants is presented in **Figure 9** (Saarikko et al., 2023).

Pregnant women (n=54) with overweight or obesity had a median (IQR) BMI of 30 (27,33), over half (56%) of the participants had a secondary education as their highest qualification, and 67% had one or more children. Gestational diabetes was diagnosed in 28% of the participants, and 46% went through induced birth.

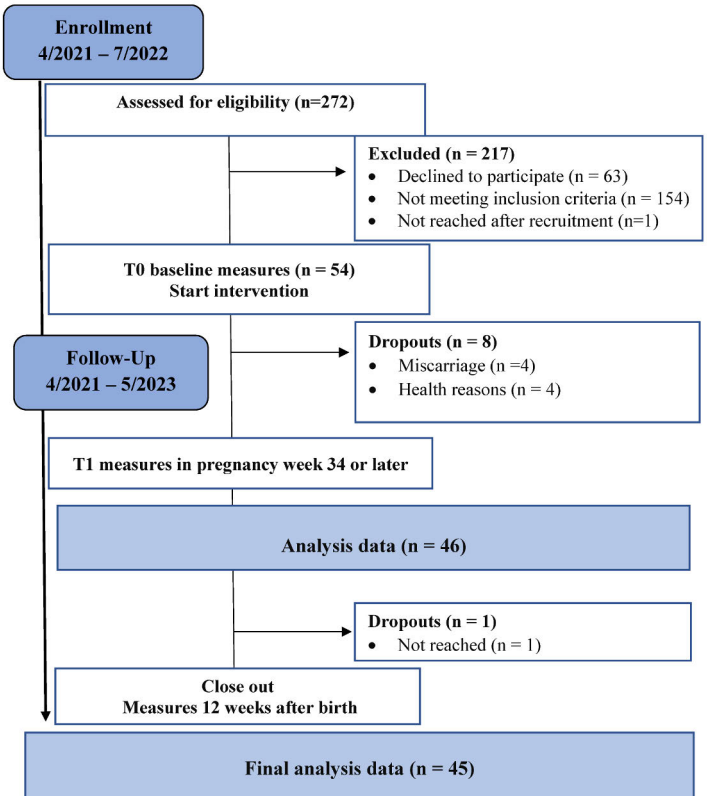


Figure 9. Flowchart of the participants (from Saarikko et al., 2024, original publication IV).

5.4.2 Outcome measures and data collection

In substudy III, the primary outcomes for assessing the intervention's effectiveness were self-efficacy in eating and PA as measured by the Weight Efficacy Life-Style Questionnaire (WEL) and the Physical Activity Self-Efficacy scale (PASE). The WEL included 20 items related to negative emotions, food availability, social pressure, physical discomfort, and positive activities that were scored on a Likert scale from 0 (not confident) to 9 (very confident), with total scores ranging from 0 to 180 (Clark et al., 1991). The PASE comprises five items evaluating confidence in exercising, with responses on a Likert scale from 1 (not at all confident) to 5 (extremely confident), and total scores ranging from 5 to 25 (Marcus et al., 1992). Higher scores on both scales indicated greater perceived self-efficacy (Saarikko et al., 2023, original publication III).

A secondary outcome, weight gain during pregnancy, was recorded by PHNs at each antenatal appointment, typically about eight times. The women's weight before giving birth was compared to national recommendations based on their prepregnancy

BMI (IOM, 2009). Postpartum weight retention or loss was assessed by comparing the weight taken 12 weeks after delivery to the prepregnancy weight (Saarikko et al., 2023, original publication III)

Maternal background characteristics, such as age, BMI, marital status, educational background, and employment status were collected using the SLIM application. Patient records were used to gather information on pregnancy and birth, including newborn data. The Edinburgh Postnatal Depression Scale (EPDS) assessed depression symptoms, with higher scores (ranging from 0 to 30) indicating more severe symptoms. A score of 10 or above was used to suggest possible depression (Cox et al., 1987). Well-being data were collected through various methods: participants wore the Oura rings continuously starting from gestational week 15 or less and continued until the postnatal visit 12 weeks after delivery. The smart ring tracked PA and sleep. Participants used an electronic food diary to record dietary intake and total daily calories. The outcomes and instruments used are summarized in **Table 4**. Participants completed the questionnaires through the SLIM application at recruitment (before 15 weeks of pregnancy), at 34 weeks of gestation, and 12 weeks postpartum. They also completed the food diary at the same time points (Saarikko et al., 2023, original publication III).

Table 4. Outcomes and instruments used in the study.

Outcome	Instrument
Self-Efficacy	
• **Eating self-efficacy**	Weight Efficacy Lifestyle questionnaire, WEL (Clark et al, 1991)
• **Physical activity self-efficacy**	Physical Activity Self-Efficacy scale, PASE (Marcus et al, 1992)
Weight gain	Patient records
Health parameters	
• **Depression symptoms**	Edinburgh Postnatal Depression Scale, EPDS (Cox et al, 1987)
• **Background characteristics**	Self-Administered Background Information Questionnaire
• **Pregnancy and delivery outcomes**	Patient records
Well-being data	
• **Data on dietary intake**	E-food diary, FatSecret mobile application (FatSecret, 2022)
• **Data on physical activity and sleep**	Oura ring (Oura, 2019)

5.4.3 Process evaluation

A process evaluation was conducted using a mixed-methods approach. The implementation outcomes (acceptability, fidelity, adherence, mechanism of impact, and contextual influences) were evaluated using qualitative methods. To evaluate fidelity of and adherence to the SLIM intervention, all participants were invited to participate in exit interviews at the end of the follow-up. Women with overweight (n=26) participated in the phone interviews, and PHNs (n=7) participated in the focus group interviews conducted by one researcher. A semistructured interview guide was used to cover all essential aspects of the issue. The focus group interviews lasted between 20 and 35 minutes, and the phone interviews lasted between 15 and 50 minutes. In addition, smart ring wear time and the days that women filled food diaries were analyzed. PHNs were asked to complete a logbook of SLIM-related contents regarding the participants' maternity care appointments (Saarikko et al., 2023, original publication III).

5.4.4 Data analysis methods

Statistical analysis

Background variables, WEL, PASE, weight change, EPDS, well-being data (calories consumed, smart ring parameters of PA and sleep) were described with appropriate statistics. The distribution of the smart ring nonwear time and the days on which women completed their food diaries were described using appropriate statistics. EPDS, weight change, smart ring nonwear time and food diary entries were tested for their association with changes in self-efficacy in eating and PA. To evaluate change over time between eating and PA self-efficacy and weight change, and their associations with well-being data, hierarchical linear mixed-effect models for repeated measures were used (Saarikko et al., 2023, original publication III).

Qualitative analysis

Qualitative data and recorded interviews were transcribed verbatim and transferred to a NVivo (QSR International Pty Ltd. Version 12, 2018) template. The content analysis was conducted by reading the transcripts and labeling codes using a deductive framework based on the process evaluation framework (Moore et al., 2015) by one researcher (JS), and the codebook was updated and adapted continuously. The themes were labeled with expressions that represented the participants descriptions. The initial themes were further refined based on constructive criticism and feedback provided by research team members (HN-V &

AA). Qualitative and quantitative data were integrated as part of the process evaluation to draw more robust conclusions about the intervention's effectiveness. In addition, the qualitative data was used to explain quantitative findings.

5.5 Ethical considerations

Research integrity

The study was conducted in accordance with the Helsinki Declaration, and responsible conduct in research was maintained in accordance with the guidelines set by the Finnish National Board on Research Integrity (TENK 2023). The ethical approval from the Joint Ethics Committee of the Hospital and the University were applied for substudies I, II and III. Permission to conduct the studies at maternity clinics was obtained from each of the participating municipalities according to their policies from the participating maternity clinics Nursing or Medical Director.

All the participants in substudies I-III were informed verbally and in written form with contact information. Participants were also informed about the confidentiality procedures. Participants were given time to consider participation, after which written, informed consent was obtained from each participant, including consent for accessing their medical records.

According to the Medical Research Act (9.4.1999/488), participation in the study could be withdrawn or canceled at any time without the need to justify the decision. Data from participants were collected in multiple ways, such as interviews, questionnaires, wearable devices with IoT technology, and from patient records. The personnel register of this research included participants' background information collected with questionnaires, health-related information collected with smart wearables (e.g., smartwatches and smart rings), and pregnancy-related information from patient records. Different challenges of data management had to be considered and planned carefully. All collected data underwent a pseudonymization procedure to ensure the confidentiality of personal information. Subsequent to this process, the research team members were granted access to the pseudonymized dataset. In compliance with data preservation protocols, the pseudonymized data will be securely archived for a minimum duration of five years. To ensure confidentiality and data security, the data were stored in password-secured electronic locations and paper copies were stored in a locked filing cabinet.

Vulnerability of the study participants

This study interferes with the integrity of overweight pregnant women who are particularly vulnerable. Pregnancy is an emotionally sensitive time, and obesity is

associated with a lot of negative attitudes and prejudices. Stigma can impair the experience of a positive pregnancy and further the risk of postpartum depression. Participating in a weight management study may highlight potential past negative experiences and cause a wide range of emotions, including anxiety (Nagpal et al., 2024). However, in this study, the collection of data from pregnant women with overweight is considered justified due to the distinct physiological states and health inherent to pregnancy, and therefore it is not possible to obtain comparable results from other examinees. In addition, this study is justified to increase skills and provide better tools for reducing the stigma of obesity among maternal care professionals.

If participants exhibited symptoms of depression, indicated by an EPDS score of 13 or higher, or if the EPDS survey suggested suicidal thoughts, the researchers contacted the participants and advised them to consult maternity care professionals.

This research did not cause any violating examinations or extra visits to the maternity clinics. The study procedures during data collection did not encumber participants excessively. With the help of collected data, it is possible to improve the care of pregnant women with overweight in the future.

6 Results

6.1 Development of the SLIM intervention (phase 1)

6.1.1 The target behaviors for weight management - Lack of ability, commitment, and motivation to change lifestyle (Substudy I, RQ 1)

The weight management behaviors of women with overweight or obesity (n=11) were categorized into three domains: Capability–a lack of ability to take a practical approach to lifestyle changes; Opportunity–challenges in committing to long-term changes; and Motivation–feelings of helplessness regarding the overweight. Pregnant and postpartum women with overweight, along with PHNs (n=5), emphasized the need for a consistent approach to addressing overweight during antenatal visits. This approach should aim to increase women's knowledge about healthy lifestyles and support their motivation to make changes. Additionally, there was an urgent need to continue supporting weight management after childbirth (Saarikko et al., 2021, original publication I).

In the capability category, both PHNs and women with overweight tended to avoid discussions about obesity and weight management, indicating a need for consistent methods to address the topic of overweight. Health technology could be employed to introduce the subject of weight and weight management as part of antenatal care. In addition, wearable devices could aid in evaluating women's lifestyles. The opportunity category highlighted a lack of resources as the primary reason for the absence of counseling and support during perinatal care, particularly postpartum. Family support was identified as the most crucial facilitating factor, along with motivation, by both PHNs and women with overweight. Peer support was also deemed important. The women expressed a conflict between viewing pregnancy as a motivational period for lifestyle changes and, conversely, as an excuse to engage in unhealthy habits. Concurrently, there was a consensus among the participants for the need to be offered a more assertive approach toward weight management and the provision of robust guidance. Motivation was identified as the most crucial aspect of weight management. Many women with overweight experienced low self-esteem,

which posed challenges and necessitated discreet counseling. Low self-esteem could also lead to avoidance of discussions about overweight. Despite expressing a desire to adopt healthier lifestyles for their children and awareness of the potential consequences of poor nutrition or inactivity during pregnancy, these women still found it difficult to change their behavior during pregnancy. Some women believed that a healthy lifestyle was unnecessary since weight gain was inevitable during pregnancy. However, others indicated that the responsibility for their unborn child was the primary motivator for being more conscious of their health behaviors. A theory-based approach to identifying target behaviors for weight management during pregnancy and the postpartum period suggested that future interventions should focus on providing a consistent method to address this topic during antenatal visits. This approach would increase women's knowledge about healthy lifestyles and support their motivation to make changes (Saarikko et al., 2021, original publication I).

6.1.2 Feasibility of the WIoT-technology for monitoring health parameters during pregnancy (Substudies I and II, RQs 5-6)

In substudy II, n=20 pregnant women participated starting from the mean gestational week 12 (SD 2). Valid PA data were available 75% and valid sleep data 72% of possible monitoring days during pregnancy. During the postpartum period, 54% of valid PA data and 57% of valid sleep data were available. PA decreased from the second trimester to the postpartum period, as expected. In addition, sleep minutes decreased and nightly awake minutes increased from the second trimester to the postpartum period. The resting heart rate increased 17% from 13 gestational weeks to 32 gestational weeks, and it remained at that level until delivery and then decreased to the early pregnancy level by four weeks postpartum due to hemodynamic changes. The findings suggest that the WioT technology represents a feasible tool for continuous monitoring during pregnancy (Saarikko et al., 2020, original publication II).

In substudy I, a comparison of wearable devices revealed that participants preferred smart rings, attributed to its aesthetically pleasing design and ergonomic comfort. Additional favorable characteristics included the prolonged battery life, the practicality of the associated application, and the detailed sleep analytics provided. Some negative issues were also identified: the application's lack of Finnish language capability posed a linguistic barrier.

The Samsung Gear Sport was commended for its user-friendly interface, comprehensive application features, and seamless synchronization capabilities. The Samsung Gear Sport was described as being easy to use, and the application had

many different features and synchronized automatically. However, the smartwatch was found to be uncomfortable and disturbing, especially at night. Both devices had limitations; for example, some of the participants could not wear them at work. The usability of health technology to self-monitoring is presented in **Table 5**.

Table 5. Usability of wearable devices (Scale: 1=very difficult, 5=very easy).

	Women with overweight (N = 7)	**Public health nurses (N = 6)**
Usability of Oura ring, Mean (SD)	3.5 (1.6)	4.3 (0.5)
Usability of Samsung watch, Mean (SD)	3.7 (0.8)	3.8 (1.0)
Usability of Oura application, Mean (SD)	2.8 (1.5)	4.0 (0.7)
Usability of Samsung application, Mean (SD)	3.8 (0.9)	3.2 (0.8)
Comfort of Oura ring, Mean (SD)	4.0 (0.8)	3.8 (0.9)
Comfort of Samsung watch, Mean (SD)	2.7 (0.8)	3.0 (1.4)

During the intervention development phase, the Oura application was developed further and the barriers such as lack of Finnish language no longer exist. The Oura ring was found to be more elegant and comfortable to use. As a result, the Oura ring was chosen as part of the intervention.

6.1.3 Modeling target behaviors to intervention functions (Substudy I, RQ 2)

In the workshops with PHNs, a total of five intervention functions were identified as relevant, according to BCW theory, in order to achieve the desired change from the results of the identified target behavior (Saarikko et al., 2021, original publication I): *Education* (increasing knowledge and understanding), *Training* (imparting skills), *Persuasion* (using communication to stimulate positive or negative feeling or action), *Environmental restructuring* (changing the physical or social context), and *Enablement* (increasing means and reducing barriers to increase capability). The frequency of coded phrases of COM-B components, TDF domains, and intervention functions are presented in **Table 6**.

Table 6. The number of phrases coded under each COM-B component, TDF domain, and intervention functions.

COM-B component	TDF domain	Number of coded phrases by women with overweight	Number of coded phrases by public health nurses (focus group interviews)
Capability			
Physical capability	Skills	17 (3%)	9 (3%)
Psychological capability	Knowledge	86 (14%)	24 (8%)
	Memory, attention and decision processes	37 (6%)	9 (3%)
	Behavioral regulation	25 (4%)	1 (0%)
Opportunity			
Physical opportunity	Environmental context and resources	20 (3%)	13 (5%)
Social opportunity	Social influences	54 (9%)	18 (6%)
Motivation			
Automatic motivation	Reinforcement	66 (10%)	16 (6%)
	Emotions	44 (7%)	19 (7%)
Reflective motivation	Social/professional role and identity	93 (15%)	36 (13%)
	Beliefs about capability	13 (2%)	20 (7%)
	Beliefs about consequences	35 (6%)	18 (6%)
	Optimism	11 (2%)	2 (1%)
	Intentions	15 (2%)	6 (2%)
	Goals	27 (4%)	3 (1%)
Intervention functions			
	Coercion	0 (0%)	0 (0%)
	Education	16 (3%)	6 (2%)
	Enablement	19 (3%)	28 (10%)
	Environment restructuring	23 (4%)	26 (9%)
	Incentivization	3 (0%)	4 (1%)
	Modelling	0 (0%)	0 (0%)
	Persuasion	9 (1%)	13 (5%)
	Restriction	4 (1%)	0 (0%)
	Training	18 (3%)	15 (5%)
Total N of codes		**635**	**286**

After defining the intervention functions, the theoretically specified BCT taxonomies (v1) and the mode of delivery for each BCT were selected for the

intervention implementation in accordance with the BCW theory (Michie et al., 2009, 2014). This study proposed 14 potential BCTs identified from this process. Explicit links are presented in Appendix 5. Matrix of COM-B model, TDF domains, intervention functions and BCT (v1). The most relevant BCTs were: (*1) Information about health consequences:* providing written, verbal, or visual information about health consequences of performing the behavior based on national recommendations. (*2) Goal setting (behaviour):* setting a goal defined in terms of a behavior to be achieved; for example, being physically active at least 30 minutes a day. (*3) Goal setting (outcome):* setting a goal defined in terms of a positive outcome of desired behavior; for example, weight gain goal during pregnancy. (*4) Feedback on behaviour:* providing evaluative information or feedback on the performance of the behavior; for example, how to eat healthier based on the food diary. (*5) Review behavioral goals:* reviewing behavioral goals together with pregnant women and consider modifying goals based on achievement e.g., increasing or decreasing minutes of daily PA. *(6) Self-monitoring of behaviour,* and (*7) adding objects to the environment* establishing the method to monitor and record behavior as a part of behavior change strategy e.g., active tracker to monitor daily PA (Michie et al., 2014).

1. *Information about health consequences*: provide written, verbal, or visual information about the health consequences of performing the behavior based on national recommendations.
2. *Goal setting (behavior)*: set a goal defined in terms of a behavior to be achieved; for example, being physically active at least 30 minutes a day.
3. *Goal setting (outcome)*: set a goal defined in terms of positive outcomes of desired behavior; for example, weight gain goal during pregnancy.
4. *Feedback on behavior*: provide evaluative information or feedback on the performance of the behavior (e.g., how to eat healthier based on the food diary).
5. *Review behavioral goals*: review behavioral goals together with pregnant women and consider modifying goals based on achievement (e.g., increasing or decreasing minutes of daily PA).
6. *Self-monitoring of behavior*
7. *Adding objects to the environment*: establish the method to monitor and record behavior as part of the behavior change strategy (e.g., an active tracker to monitor daily PA) (Michie et al., 2014).

6.1.4 Intervention's core components and implementation strategies (Substudy I, RQs 3-4)

The core components of the SLIM-intervention were defined as: (1) *goal setting* referring BCTs: goal setting (behaviour and outcome); (2) *motivational interviewing* referring BCTs: information about health consequences, feedback on behaviour and review behavioural goals; (3) *feedback* referring feedback on behaviour and self-monitoring of behaviour and (4) *health technology* referring BCTs: adding objects to the environment, self-monitoring of behaviour and social support. In addition, the implementation strategies were classified using the Expert Recommendations for Implementing Change (ERIC) as follows: (1) conducting educational meetings; (2) developing educational materials; (3) informing local opinion leaders; (4) mandate change; and (5) reminders (Powell et al., 2015) (Saarikko et al., 2023, original publication III).

6.2 Feasibility of the SLIM intervention (phase 2)

The process evaluation of the SLIM intervention is presented in **Figure 10**.

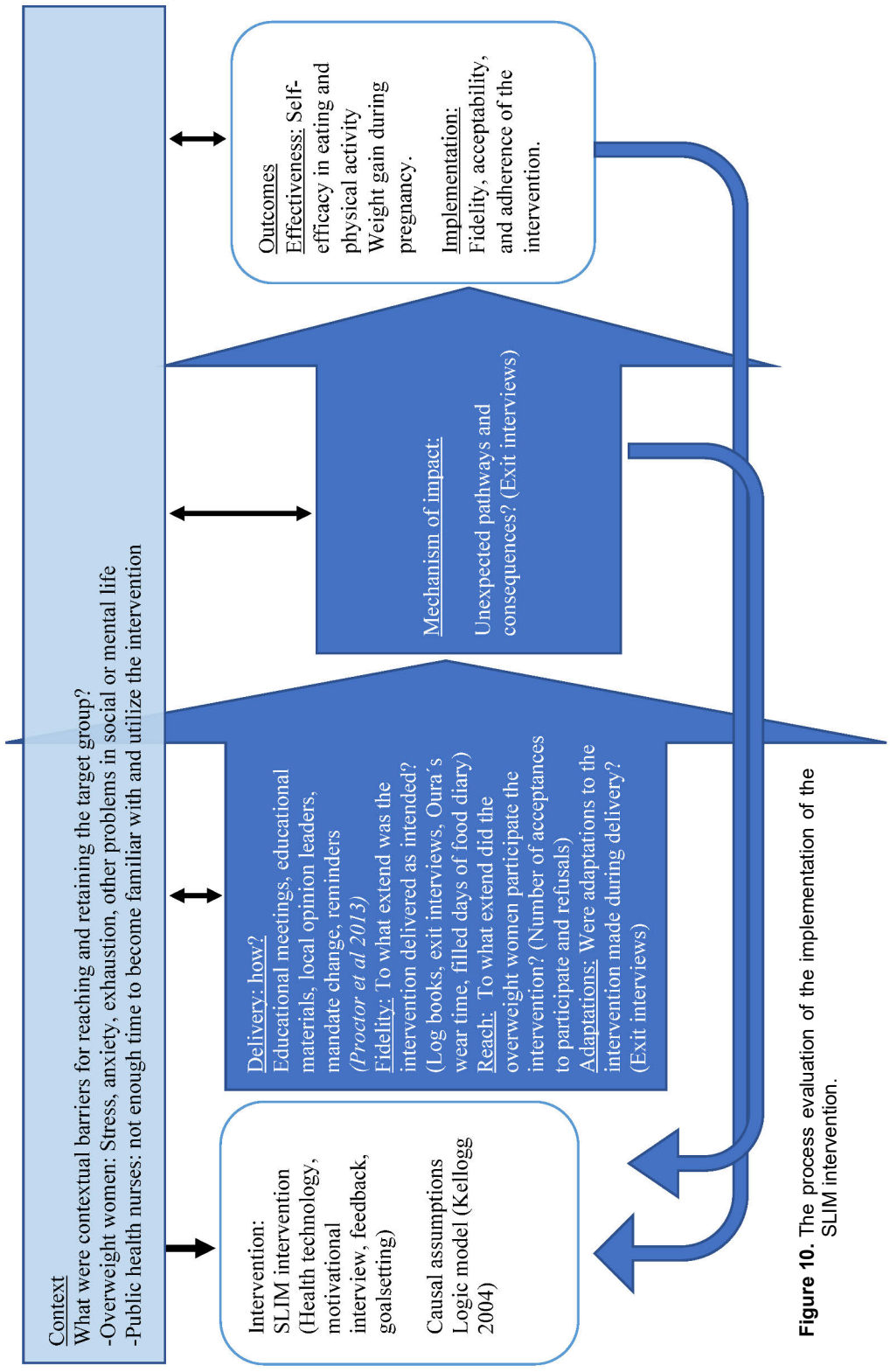


Figure 10. The process evaluation of the implementation of the SLIM intervention.

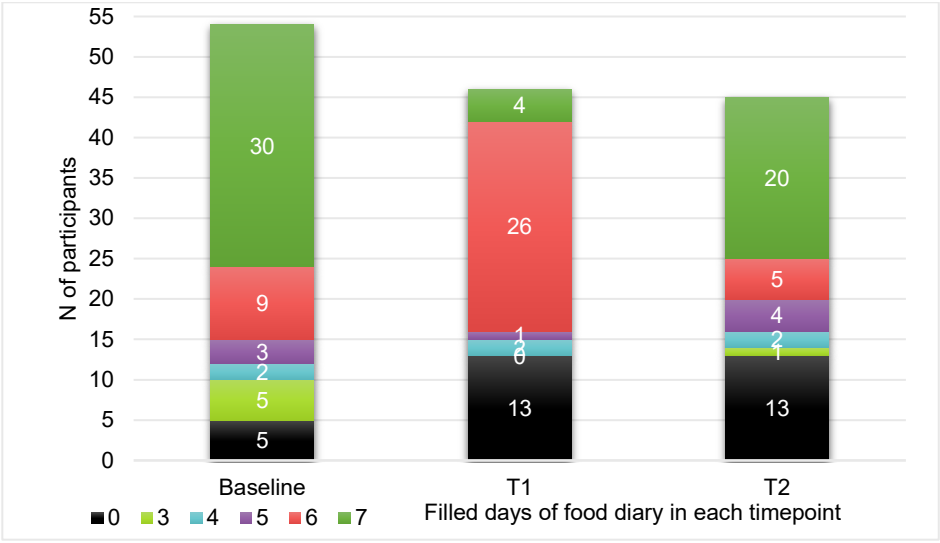
6.2.1 The effectiveness of SLIM intervention (Substudy III, RQ 7)

The SLIM intervention was not effective in increasing self-efficacy in eating or PA. The levels of self-efficacy in eating and PA were high throughout the study period, although there was a great variation between participants. Mean eating self-efficacy scores (95% CI) were 125 (115, 135), 130 (119, 141) and 125 (114, 136) *(p=0.650)* respectively across time points, and self-efficacy in PA was 15 (14, 16), 15 (13, 16) and 15 (14, 16) *(p=0.936)* at the same time points. Altogether 14 women had an EPDS score of at least 10 at the baseline indicating possible depression. These women had statistically significantly lower scores on eating self-efficacy compared to women with no depression symptoms *(p=0.009).* Altogether six women had an EPDS score of 13 or more during pregnancy and six women during the postpartum period indicating depression. Daily intake of calories, median of 1880 kcal/day or more, was statistically significantly associated with higher self-efficacy in PA *(p=0.003),* and higher educational level was statistically significantly associated with higher scores in self-efficacy in PA *(p=0.044).* The SLIM intervention was not effective on limiting weight gain during the perinatal period. However, most of the women (n=9/10), whose gestational weight gain was within recommendations or less, managed to lose weight during the postpartum period, while only a fifth of women with excessive GWG achieved a similar result *(p<0.001).* The odds of excessive GWG were higher for under 30-year-old women compared to women over 30 (Saarikko et al., 2024, original publication IV).

6.2.2 Implementation of the SLIM intervention (Substudy III, RQ 8)

Fidelity of the intervention

Fidelity of the intervention, in terms of smart ring nonwear time, was statistically significantly associated with self-efficacy in PA. Participants whose nonwear time of the smart ring was at most 237 minutes per day had a 1.5 [0,3] times higher score in PA self-efficacy (Saarikko et al., 2024, original publication IV). Participants filled electronic food diaries 78%, 53% and 52% out of potential days in the gestational week < 20 (baseline), gestational week 34 (T1), and 12 weeks postpartum (T2) respectively, numbers are presented in more detail in **Figure 11**.



Baseline: pregnancy week <15, T1: pregnancy week 34, T2: 12 weeks postpartum

Figure 11. Distribution of food diary fill-in days at each time point.

Adherence to the intervention

PHNs unanimously stated that the logbooks assumed to be filled in during the visits were ineffective. Due to the use of several patient record platforms, they constantly forgot to fill in the logbooks. Some PHNs reported discussing the intervention elements with the participants occasionally, while others believed that they utilized the intervention in every appointment.

> *"...We document so much, we have IPANA and Pegasos... so we just talk about it, but when the logbook is somewhere, we have only documented a few funny ticks... It does not tell the truth. And there's no way you can dig these up afterwards from these patient records. No, it's an impossible task..."* (PHN 1)

Women with overweight told conflicting stories. Many women thought that intervention was not utilized at all during maternity care visits and wished that they had utilized it. Conversely, some participants were very satisfied with the intervention and said they had talked about it during appointments.

> *"...somehow, they could at least ask. It may have been that I would have paid more attention to myself...Maybe I would have liked a different approach to this issue ..."* (ID125)

PHNs reported that regular educational meetings with researchers were the most motivating and important strategy to keep them involved in the intervention.

> *"...It makes a huge difference, if you had just sent an email every now and then, so I would argue that it might not have been as functional as now, when you came there and were active yourself..."* (PHN 3)

Contextual influences in the implementation – Change is new normal

PHNs characterized the continual alterations in their professional responsibilities as a significant burden. The onset of the pandemic marked the beginning of these modifications, compelling PHNs to redirect their focus toward conducting COVID-19 tests and administering vaccines, thereby impacting their routine duties. Subsequent to the pandemic, substantial organizational restructuring occurred, most notably the shift to the Well-being Services Counties. PHNs described these transformations to have a detrimental effect on the implementation of the intervention.

> *"...Especially during the pandemic, it was really hectic. And that workload… so the appointments were shorter, so do you really have time to focus on this…"* (PHN 1)

Concurrently, PHNs acknowledged that alterations in their work are an inherent aspect of their profession. They perceived the intervention as beneficial for a subset of participants. PHNs noted that women who were motivated toward personal health maintenance were more amenable to guidance. Conversely, those facing additional challenges in managing their life presented greater difficulty in terms of motivation and consequently derived fewer advantages from the intervention.

Mechanism of impacts - Technology as a part of intervention

PHNs posited that the intervention might be incorporated into maternity clinics at some point in the future. They expressed an aspiration for the allocation of resources that would enable the efficient synchronization of data procured from health technology with their electronic patient record systems. Moreover, they advocated for additional time to facilitate comprehensive discussions pertaining to health data with the women.

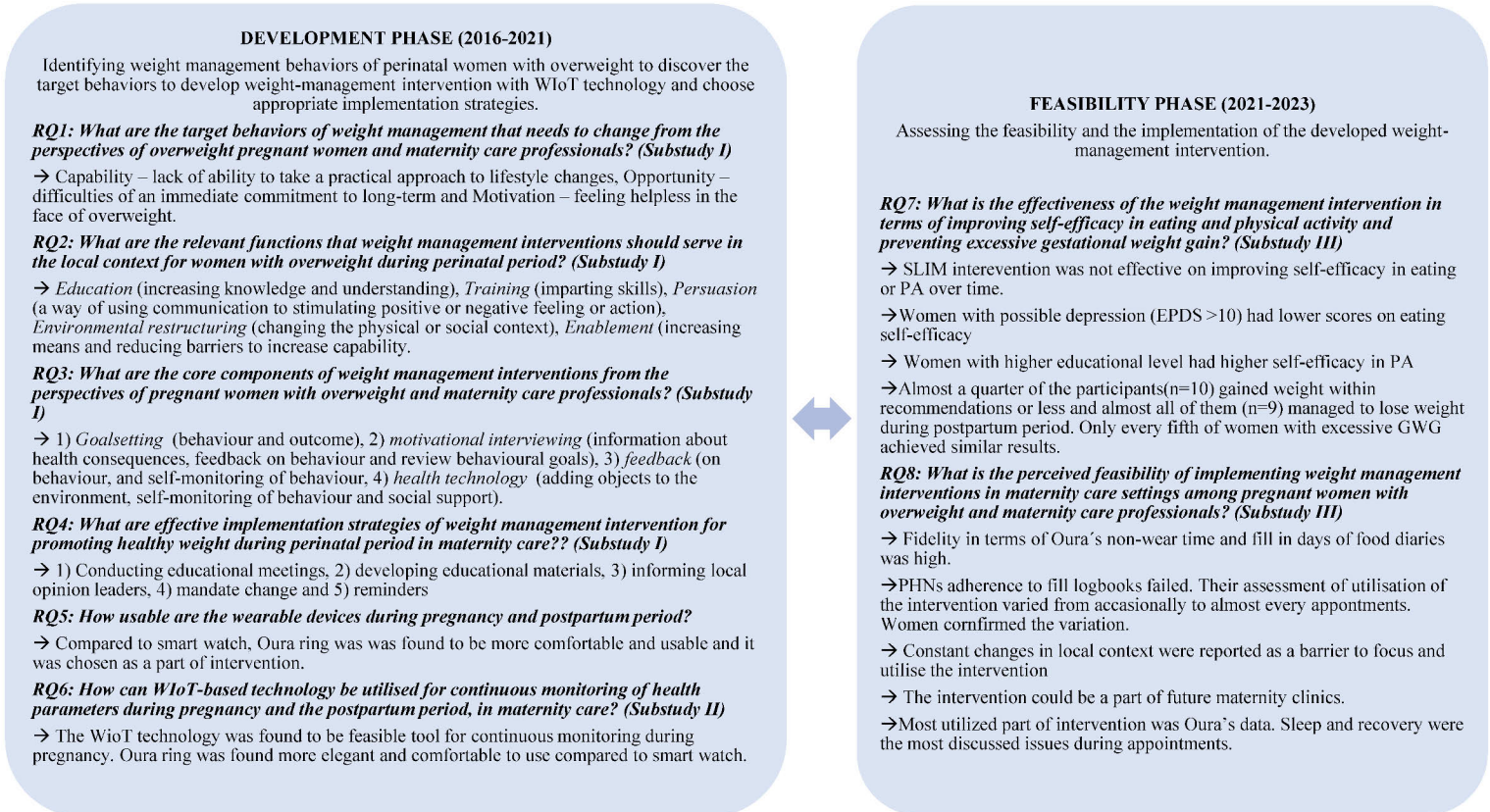
Most utilized part of intervention was smart rings data. Focus on sleep and recovery emerged as the central theme in the dialogues between the PHNs and the women with overweight during their appointments.

> *"... as far as sleep is concerned, if I've had a really bad night, I've slept more easily during the day, I've given myself permission to take those naps…"* (ID133)

Data on PA were deemed efficacious in facilitating the attainment of daily targets. Concurrently, the employment of a food diary proved to be efficacious in stimulating the distribution of food consumption or eating intervals. Women with overweight envisioned that technology should be utilized more in maternity care, although a contingent of the study participants expressed a dissenting view, questioning the efficacy of the intervention.

6.3 Summary of the main results

The main findings of this study are summarized in **Figure 12**.



RQ: Research question

Figure 12. The main findings of the study.

7 Discussion

7.1 Discussion of the results

The main findings of the development phase of the study and the subsequent feasibility phase, along with their relationship to the existing literature, are discussed below.

7.1.1 From target behaviors to development of the intervention and implementation strategies

The main findings of the development phase were contradictory perceptions about weight-related guidance in maternity care, time constraints during perinatal appointments, and the feasibility of a WIoT-based system. Overall utilization of the aforementioned barriers and facilitators to cocreate the intervention are discussed in this chapter.

The weight management behaviors and attitudes of both maternity care professionals and women with overweight were identified, and a theory-based approach was employed to clarify the target behaviors of women with overweight or obesity. Women with overweight reported that they did not receive sufficient information about the risks associated with obesity, whereas PHNs indicated that they provided adequate information. Consistent with our findings, Lindhardt et al. (2013) reported that pregnant women with overweight or obesity felt inadequately informed about weight-related risks and additional check-ups, suggesting that discussing GWG with pregnant women with overweight or obesity can be challenging for maternity care professionals (Christenson et al., 2019; Faucher & Mirabito, 2020). One reason for this is probably the fact that the women felt judged and that the maternity care professionals had placed them in a special category. In a study of Lindhardt et al. (2013), pregnant women with overweight or obesity also reported feeling accused by their care providers. PHNs may feel uncomfortable talking about weight and GWG limits (Heslehurst et al., 2013), and this can lead to PHNs choosing alternative words for obesity, making it seem less stigmatizing (Kominiarek et al., 2015). Maternity care professionals probably recognize the importance of informing women about the implications of a high BMI and excessive

GWG during pregnancy, but they might hesitate or delay these discussions due to uncertainty about how to communicate effectively without causing offense, shame, stigma, discouragement, or anxiety (Holton et al., 2017). Kominiarek et al. (2018) identified several barriers to communication, including stigma associated with obesity, making women feel uncomfortable, professionals feeling uncomfortable with their own weight, professionals feeling judgmental or overly negative, and professionals feeling they are limiting women's choices. The study suggested that educating maternity care professionals—such as training in motivational interviewing in the implementation of maternal care pathways—would be useful in avoiding stigma and maximizing the support of women with overweight in maternity care. It is essential to provide adequate training and education on recognizing weight stigma, facilitate sensitive discussions about GWG, and encourage reflective practices to identify personal biases (Nagpal et al., 2024).

The limited time available in relatively short appointments often hinders the ability to comprehensively address all aspects of antenatal care. This time constraint makes it challenging to build or maintain trust and to discuss the sensitive topic of GWG (Walker et al., 2019). In addition, the PHNs described a lack of resources as the reason for an absence of support after birth and explained that weight management was not part of standard care (McCann et al., 2018; Olander et al., 2019). Addressing these time constraints in antenatal appointments is an important factor for providing comprehensive care. More effective utilization of technology in addition to follow-up appointments or routine check-ups can save time and reduce the need for in-person visits (Haleem et al., 2021; WHO, 2021). Technology was also a component that participants wanted or expected to somehow be a part of the intervention in maternity clinics. Technology is already a part of everyday life and has raised the question of why it is not used more effectively in healthcare. However, the utilization of technology is not entirely unambiguous. For example, it is well known that wearable devices might under- or overestimate the levels of PA or sleep (Fokkema et al., 2017; Wahl et al., 2017). In addition, the devices had not been validated among pregnant women.

The WIoT-based system was found to be feasible to monitor health parameters (PA, sleep, and heart rate) during pregnancy. A smart wristband can be used to indicate the level of PA to a pregnant woman and support her in changing her lifestyle. In line with previous studies, PA decreased during pregnancy and was quite low in the third trimester and during the postpartum period (Hayes et al., 2015; Nascimento et al., 2015) Sleep quality declined starting from the first trimester, and both the number and duration of nocturnal awakenings increased as pregnancy proceeded (Mindell et al., 2015; Wilson et al., 2011) and in the postpartum period (Bei et al., 2015). It also appeared that a smart wristband was an appropriate tool for measuring heart rate during pregnancy; the resting heart rate increased until 32

gestational weeks, which is a normal hemodynamic change during singleton pregnancy (Hunter & Robson, 1992).

The barriers to weight management that were identified in maternity clinics, such as methods to broach the topic of overweight, difficulties in motivating women, inconsistent counseling, and awareness of the risks of excessive weight gain during pregnancy were found to be potential topics for intervention. Facilitators, such as goal setting, individual and discreet counseling, and support from family and partners were suggested as potential ways to support women. The next step was to identify intervention functions and BCTs by categorizing identified target behaviors to the applicable BCW intervention functions and further BCT categories (Michie et al., 2014). The most relevant BCTs of this study were consistent with the previous studies that resulted in the BCTs: goal setting of behavior, self-monitoring of behavior, feedback on behavior, feedback on the outcome of behavior, adding objects to the environment (e.g., using a diet logbook or a wearable smart device), were associated with positive intervention effects (Dombrowski et al., 2012; Michie et al., 2009; Samdal et al., 2017).

The intervention development process was strengthened by its theory-based, systematic approach and cocreation with PHNs. The objectives of incorporating cocreation principles in developing weight management interventions were to ensure that the intervention's components and strategies were evidence-based and tailored to the diverse needs and preferences of the target individuals. Additionally, the collaborative approach aimed to improve the relevance, effectiveness, and sustainability of these interventions (Greenhalgh et al., 2016).

7.1.2 Evaluation of the intervention and the implementation

The following findings of the feasibility phase, lack of effectiveness on self-efficacy or weight change, benefits of following GWG recommendations, and gaps in the implementation process are discussed below.

Effectiveness of the intervention

The intervention had no effect on self-efficacy or weight change of women with overweight or obesity during perinatal period. Contrary to the results of this study, Joki et al. (2020) highlighted the critical role of self-efficacy in achieving weight management success. Self-efficacy enabled the participants to be self-confident about being able to influence their lifestyles despite challenges in life such as divorce, pregnancy, parenting, or starting a new job. Selecting self-efficacy as a primary outcome was justified, because self-efficacy beliefs significantly influence the adoption of healthy behaviors, the cessation of unhealthy behaviors, and the

maintenance of behavioral changes despite challenges and difficulties. In addition, all major health behavior theories, such as the Health Belief Model (Rosenstock et al., 1988) and the Theory of Reasoned Action/Planned Behavior (Ajzen, 1985; Fishbein, 2008), include self-efficacy as a key component. Furthermore, research has shown that enhancing self-efficacy beliefs is crucial for the successful initiation and maintenance of nearly every health-related behavior, including exercise (Kassavou et al., 2014) and diet (Berman, 2006).

The SLIM intervention components were designed to enhance and elevate self-efficacy. Effective goal-setting has been shown to increase self-efficacy across various domains, including health-related behavior changes (Bailey, 2019). Verbal persuasion (Bandura, 1977), another method to boost self-efficacy, was implemented through motivational interviewing and feedback provided by PHNs. A meta-analysis identified that action planning, prompt self-monitoring of behavioral outcomes, planning social support/social change, and time management were significantly correlated with increased self-efficacy (Olander et al., 2013). A potential reason for the intervention's lack of effect on self-efficacy or weight change could be the insufficient incorporation of social support within the intervention framework.

The findings demonstrated that following gestational weight gain recommendations facilitate weight loss after giving birth. The findings align with meta-analysis (Rong et al., 2015), underscoring the significance of adhering to GWG recommendations to prevent postpartum weight retention. The results also indicated that women exhibiting the possible symptoms of depression, as well as those with lower educational attainment, may derive advantage from augmented support measures. This finding suggests a need for differential intervention strategies that are specific to the psychosocial profiles and educational backgrounds of the participants, thereby enhancing the efficacy of support provided during the perinatal period. Pregnancy can be a stressful period, and pregnant women with overweight or obesity might face additional anxiety or concerns about their health or the health of their baby. Emotional factors could hinder their ability to commit to behavior changes. In addition, social norms and low education levels can significantly influence a pregnant woman's behavior. If the intervention did not consider or address these factors enough, it may have contributed to the lack of effectiveness of the intervention. Furthermore, our results showed that the odds of excessive GWG were higher for under 30-year-old women compared with women over 30. This may be caused by different metabolic rates and energy needs, or younger women might have different lifestyle habits, such as dietary choices and PA levels, which could influence weight gain patterns during pregnancy (Zhou et al., 2022) Younger women may also have lower socioeconomic status which can limit access to healthy food options. In addition, they may experience higher levels of stress due to education,

career, or financial instability, which can contribute to weight gain (Darling et al., 2023).

The questionnaires, WEL and PASE, were selected for this study specifically to measure self-efficacy related to weight management. The WEL was developed and validated to evaluate the role of eating self-efficacy in treating obesity and is widely used in both clinical and research settings to assess self-efficacy related to weight management. The WEL assesses an individual's confidence in resisting the urge to eat in different scenarios. This makes it especially valuable in obesity treatment programs, as it aids in customizing interventions based on the patient's self-efficacy levels (Clark et al., 1991). In addition, the PASE was chosen to complement the evaluation of self-efficacy in weight management. It is used to measure an individual's confidence in their ability to engage in PA assesses beliefs about maintaining regular exercise routines, typically focusing on the frequency, duration, and intensity of PA (Marcus et al., 1992).

The population used for the power analysis, based on WEL and PASE measures, was not fully representative of the actual study population, and this could affect the accuracy of the power analysis. In addition, the sample size was calculated for a one-tailed test. However, two-tailed tests were used, which may lead to underestimation of the required sample size. If the sample size was not sufficient, the study might lack the power to detect a statistically significant effect, even if one exists.

Implementation of the intervention

The high fidelity of the intervention, regarding the participants' compliance with Oura's nonwear time and the consistency in completing food diaries suggests that the participants were engaged and complied well with the intervention. However, there was a discernible deficiency in the PHNs' compliance with logbook documentation, highlighting the need for improved systems to ensure data accuracy and regulatory adherence indicating a gap in the implementation process from the maternity care professionals' side. Although PHNs received education before the intervention started, they might have lacked adequate training because of high turnover within the staff. Based on the results of the exit interviews, educational meetings with PHNs every six months were probably not enough for them to implement the intervention in a standard, effective way. Similar to previous studies (Olander et al., 2019; Walker et al., 2019), PHNs reported that they have limited time per patient due to the high volume of pregnant women. They reported prioritizing various aspects of prenatal care, which took precedence over weight management interventions. This probably made it difficult to allocate sufficient resources and attention to addressing weight management. Implementing comprehensive weight management interventions requires time for counseling, education, and support,

which might be challenging within the constraints of prenatal care appointments (Bick et al., 2020; Taylor et al., 2020).

PHNs also characterized the continual alterations to their professional responsibilities as a significant burden. Maternity clinics lacked resources to effectively counsel and support pregnant women with overweight. This deficiency has probably hindered successful intervention implementations. Furthermore, the follow-up period of the intervention was overshadowed by the pandemic, which limited the resources further. A recent meta-analysis reported a significant decrease in the number of antenatal clinic visits, although results also showed an increase in virtual or remote antenatal care (Townsend et al., 2021).

Motivating pregnant women with overweight to actively engage and comply with weight management interventions can be challenging. Pregnancy itself can be a time of stress and varied emotional experiences, affecting a woman's ability to commit to behavior changes. In addition, individuals with overweight or obesity, including pregnant women, often face a stigma and discrimination (Christenson 2020, Faucher 2020) which can impact their willingness to seek or engage in weight management interventions due to the fear of judgment or mistreatment. In addition, PHNs working in maternity care might face challenges discussing weight management in a sensitive and nonstigmatizing manner without causing distress or stigma to pregnant women. Some maternity care professionals might feel uncomfortable or inadequately trained to discuss weight management with pregnant women (Lavender & Smith, 2016). This discomfort can hinder open communication and effective implementation of interventions. Although this intervention was developed in collaboration with pregnant women who were overweight, it might not consider the unique needs and concerns of all pregnant women with overweight. However, the need for clear and direct information, and improved interactions with maternity care professionals, to better support women’s weight management behavior is inevitable (Sánchez et al., 2021). In addition, women's social networks play a vital role during pregnancy. The intervention should have included people in women’s social networks to facilitate engagement and adherence, because if the intervention lacked adequate support or guidance, adherence to behavioral changes will not last.

It is also notable that the refusal rate for the intervention was high, and the most common reason was that the women didn't have the strength or resources for anything other than necessary action. Women who had the most problems in their lives and would have benefited the most from the intervention were likely to opt out of the study. In addition, some participants dropped out of the study due to fatigue and depressive symptoms. There is an urgent need to identify these women and orient more support for them.

7.2 Validity and reliability of the studies

The validity, reliability, strengths, and limitations of the whole research process, and in particular, literature review, data collection procedures, and instruments used in this study are discussed in this chapter. This research consisted of three substudies that applied a variety of designs, and data collection and analysis methods followed the MRC framework for complex interventions (Skivington et al., 2021) that guides the development of evidence and theory-based interventions. In addition, the implementation-of-change model (Grol et al., 2013) guided the development process of the weight management intervention. The theory-based approach can be considered one strength of this study.

7.2.1 The literature review

The reliability of the literature review of this study was ensured with the umbrella methodology, which combined numerous reviews and existing evidence on the subject (Aromataris et al., 2015). Literature searches were carried out against six databases, and due to the overlapping search results, it is unlikely, although possible, that relevant studies were missing from the results. However, the review has a few limitations. A systematic quality evaluation of the selected studies was not conducted. In addition, the selection and evaluation process of the reviews was done by only one researcher.

7.2.2 Development of the intervention

The strength of substudy I was a theory-based approach to describe target behaviors of the intervention and implementation strategies. This approach permitted the more comprehensive assessment of potential barriers and facilitators to the target behaviors. To ensure credibility of the study, methodological triangulation was used by gathering data by means of different data collection methods such as individual interviews of women with overweight, focus group interviews of PHNs, and field notes. In addition, investigator triangulation was applied by involving three researchers in the organizational aspects of the study and in the process of data coding, analysis, and interpretation of decisions. To enable the assessment of transferability, the descriptive data, such as the context in which the research was carried out, its setting, sample, sample size, demographic, socioeconomic, and clinical characteristics, inclusion and exclusion criteria, interview procedure, and topics were provided. The BCW theory suggested the themes of the interview guides, and they were piloted with the first interview to ensure appropriateness and understandability of the questions. To enhance the applicability of the findings, a

purposive sample of perinatal women who were overweight or obese and PHNs working in maternity clinics were employed to gather information from different perspectives on weight management during the perinatal period. The sample of women who were overweight could have been biased due to refusal of participating in the study because of the sensitive subject. To improve dependability, detailed records of all the steps in the research process, including data collection, analysis, and decision-making, were described. The research process and findings were discussed with the research team until a consensus was reached (Korstjens & Moser, 2018).

The strength of substudy II was the lengthy data collection period to evaluate the feasibility of the WIoT technology for continuous monitoring during the perinatal period. However, the potential for generalizability was reduced due to the study's feasibility design, the use of a convenience sample, and the small sample size. In addition, the nonwear time of the smart watch might have affected the results even though the data during pregnancy were found to be representative and covered the long follow-up period well. During the postpartum period other methods of monitoring should be considered.

The strength of the intervention development process was the cocreation approach where end users were involved in the complete process. This enabled PHNs to be part of the decisions about which intervention functions and BCTs were important and how the interventions' core components should be designed. The authenticity and credibility of the workshops were ensured by audio recording the discussions, writing field notes, and creating mind maps. However, observer bias was possible because only one researcher conducted the workshops. Moreover, the methodology of cocreation has been significantly strengthened in recent years. The lack of application of methodologies such as design thinking (Mendini et al., 2021) may potentially explain the weak results observed in this study.

The results supported the preliminary reliability of a smart wearable with IoT technology. However, more research was needed to validate the continuous monitoring of pregnant and postpartum women. It is also notable that in the intervention, the data of WIoT was not meant to evaluate the specific levels of PA or sleep. Instead, the purpose was to utilize the data to set personalized goals and evaluate them together with PHNs. A wearable device that would be usable during the long follow-up period was chosen. In substudy I, women with overweight and PHNs both compared wearable devices. The Oura ring was preferred over the smartwatch especially because of its long-lasting battery and specific sleep information. It was also found to be more comfortable to use.

7.2.3 Feasibility of the intervention

In substudy III, several aspects of designing the quasi-experimental trial were noted to enhance reliability. We estimated the sample size in advance based on power calculations and methodological literature. The desired sample size was achieved after including an additional maternity clinic in the study. We tested the intervention in the participants' everyday environments, such as maternity clinics and their homes, and included the assessment of a range of parameters to establish the associations for the intervention outcomes. However, this study has several limitations. First, the nonrandomized study design introduces a risk of selection bias. Factors like socioeconomic status may influence participation and outcomes, complicating the attribution of changes solely to the intervention.

Without randomization, other variables could also impact the results, making it challenging to establish a clear cause-and-effect relationship. Additionally, the findings may not be broadly applicable due to the lack of controls for various influencing factors such as psychological and socioeconomical factors in different settings. Nevertheless, given the limited knowledge about weight management in overweight perinatal women, the nonrandomized pre-post study design serves as a starting point for generating hypotheses and exploring potential relationships. Furthermore, the long follow-up time allows for examining changes over time among the participants, providing valuable insights into trends and patterns.

The high fidelity of the intervention, regarding the participants' compliance with Oura's nonwear time and the consistency in completing food diaries suggests that the participants were engaged and complied well with the intervention. However, there was a discernible deficiency in the PHNs' compliance with logbook documentation, highlighting the need for improved systems to ensure data accuracy and regulatory adherence indicating a gap in the implementation process from the healthcare providers' perspective.

7.2.4 Instruments

In substudy III, validated instruments: Weight Efficacy Lifestyle (WEL) questionnaire, Physical Activity Self-Efficacy scale (PASE) and Edinburgh Postnatal Depression Scale (EPDS) were used. WEL questionnaire is a standard, validated, and clinically significant tool for measuring eating self-efficacy. The eating self-efficacy score is derived by totaling all the items, with higher scores indicating greater eating self-efficacy. Validation studies have demonstrated internal consistency for Cronbach's α ranging from 0.70 to 0.90 in an overweight Caucasian population. External validity of the WEL has also been supported, as changes in WEL scores were observed during obesity treatment (Clark et al., 1991). The PASE

questionnaire is a validated tool for assessing confidence in the ability to exercise when encountering specific barriers. In a sample of Latina women, the internal consistency for Cronbach's α ranged from 0.70 to 0.78 (Marcus et al., 1992; Mendoza-Vasconez et al., 2018). However, neither the WEL nor the PASE questionnaires have been validated for perinatal women with overweight or obesity, which is recognized as a limitation. Consequently, the results may not be fully reliable or generalizable to this target population. The EPDS is a reliable and valid ten-item questionnaire designed to screen women for symptoms of emotional distress during pregnancy and the postnatal period. Among an unselected sample of 845 pregnant women, the reliability values of the EPDS, as indicated by Cronbach's α coefficient per trimester, were 0.82, 0.83, and 0.84, respectively (Bergink et al., 2011; Cox et al., 1987).

In substudy I, the semistructured diaries and questionnaires developed for the purpose of this study were used to collect information of user experiences regarding wearable devices. Although previously validated instruments were not used, the diaries and questionnaires were considered appropriate for the purpose of this substudy.

Several wearable devices were used in this study. Garmin Vivosmart (HR, Garmin), that was used in substudy II to collect continuous data of health parameters, had shown an acceptable level of validity for step counts (Fokkema et al., 2017; Wahl et al., 2017) and sleep time compared to a sleep diary in a healthy adult population (Lee et al., 2018). The Samsung Gear Sport watch was used in substudy I. In a sample population of healthy adults, the sleep parameters of the Samsung watch had indicated significant correlations with actigraphy (Mehrabadi et al., 2020). The Samsung watch also showed validity for PA measurements (Davoudi et al., 2019). All devices, which estimate PA intensity based on heart rate elevation, might not be reliable because the resting heart rate increases and the maximal heart rate decreases during pregnancy, resulting in a smaller heart rate reserve (Garmin, 2017; Mehrabadi et al., 2020). The Oura ring was used in substudy III, as part of the SLIM intervention to collect health data on activity level and sleep. Previous studies have indicated the reliability of the Oura ring on measuring sleep, PA, heart rate, and heart rate variability (Cao et al., 2022; Mehrabadi et al., 2020; Niela-Vilen et al., 2022). Oura measures PA with a 3D accelerometer, which is used to assess movement, steps, and type of activity. By combining this data with age, weight, height, and gender, Oura converts these into the units of energy consumed for activity (Oura, 2023), meaning that Oura is supposedly more reliable at measuring PA levels during pregnancy. On the other hand, some participants reported problems using the Oura ring—for example, due to a swelling of the fingers as the pregnancy proceeded. This problem increased the nonwear time of the Oura ring and had an impact on reliability. In conclusion, one limitation was that none of these devices had been

validated by pregnant women. In addition, some participants could not wear the Oura ring at work.

The FatSecret application was part of the SLIM intervention and was used as a tool to collect data on dietary intake in substudy III. FatSecret had been found to be accurate and practical in previous research (Ferrara et al., 2019). Previous research has also shown that the use of mobile applications versus conventional techniques (typically paper records) may result in better self-monitoring adherence and improvements in dietary intake (Lieffers & Hanning, 2012). One notable limitation is that nutrition information that is viewable while using the food diary might improve dietary reporting (Carter et al., 2013).

7.3 Implications and future research

The following suggestions for practical implications are presented based on this study:

1. Overweight, obesity, and related risks should be directly addressed during maternity clinic appointments and more effective strategies to support women in achieving their weight management should be refined.
2. When designing policies and programs in maternity care, the need for knowledge and support for pregnant women with overweight regarding a healthy lifestyle should be considered.
3. Highlighting the possibilities of health technology, such as utilizing the data of WIoT to personalize lifestyle guidance in maternity care, could be better noticed in nursing recommendations, guidelines, education, and practice.
4. The role of continuous support and feedback, especially from peers and family, needs to be addressed more comprehensively in health education on weight management.
5. The broader societal implications, such as recognizing the impact on public health outcomes, reducing healthcare costs associated with obesity-related complications, and promoting healthier future generations should be addressed in designing policies and programs to support pregnant women with overweight or obesity.

This study strengthened the body of research on WIoT-based weight management of women with overweight or obesity the during perinatal period. Still, there is a need for future research on these topics. The following suggestions are presented:

1. The presented components of SLIM intervention were recognized based on a qualitative descriptive study. Further research confirming these findings and

examining the correlations and causalities of the presented core components and health literacy is needed.

2. The implementation of SLIM intervention should have been more systematic and effective. Support from management is essential for the implementation of the intervention to integrate it into practice. In addition, educational sessions should have been more precise and repeated more often. Conducting formative research with these elements would assist the further development of SLIM intervention.
3. The effectiveness of SLIM intervention was evaluated in increasing self-efficacy in eating and PA and limiting weight gain during pregnancy. Further research examining these elements and how to support weight management of pregnant women with overweight or obesity is more comprehensively needed. Evaluating the SLIM intervention using a randomized controlled trial (RCT) design and a logic model would provide stronger evidence of its effectiveness.
4. The results support the use of SLIM intervention as an additional method in maternity care for providing personalized health education. Conducting a more comprehensive process evaluation of SLIM intervention would contribute to the implementation of SLIM and understanding the mechanisms of the effects.
5. Further development of SLIM intervention is needed: Integration to an existing patient record should be done. Conducting formative research with these new elements would assist the further development of SLIM intervention.

8 Conclusions

The study raises awareness about the importance of weight management among women with overweight or obesity during the perinatal period The findings of the study demonstrated that following gestational weight gain recommendations facilitates weight loss after giving birth. The substantial association between excess GWG and PPWR indicates that high-quality confirmatory studies on interventions on diet, PA, and psychobehavioral components are clearly needed to address the issue of excess weight gain during pregnancy. In addition, women with signs of depression or women who have lower educational levels were found to have lower self-efficacy levels. This finding indicates that these groups could benefit from additional support tailored to their needs.

In addition, the study provides practical insights for maternity care professionals on the challenges and barriers faced by pregnant women with obesity in adhering to weight management interventions. The utilization of the intervention by PHNs demonstrated that they probably would have needed more resources to be able to implement the intervention effectively. The variability in adherence to the utilization may have consequentially influenced the effectiveness of the intervention. However, our results suggested that the intervention, particularly the use of Oura's data, has been a valuable component during maternity clinic appointments. This finding indicates that the intervention is well received and could be a beneficial addition to future maternity care services.

This study serves as a starting point for generating hypotheses in future studies by highlighting the challenges and potential areas for improvement in interventions. The findings offer valuable insights into the effectiveness of using WIoT technology in behavioral interventions. By identifying the limited success in achieving primary outcomes, this study underscores the need for more tailored and comprehensive approaches. There is a need for a randomized controlled trial to test the efficacy of SLIM intervention, refined with even closer collaboration with PHNs. The leaders of maternity clinics should be committed to facilitate the implementation of the intervention, and there is a need for a more standardized approach to ensure the uniform implementation of the intervention.

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Zahrt, O. H., Evans, K., Murnane, E., Santoro, E., Baiocchi, M., Landay, J., Delp, S., & Crum, A. (2023). Effects of Wearable Fitness Trackers and Activity Adequacy Mindsets on Affect,

Behavior, and Health: Longitudinal Randomized Controlled Trial. *Journal of Medical Internet Research*, *25*. https://doi.org/10.2196/40529

Zhou, M., Peng, X., Yi, H., Tang, S., & You, H. (2022). Determinants of excessive gestational weight gain: a systematic review and meta-analysis. *Archives of Public Health*, *80*(1), 1–12. https://doi.org/10.1186/s13690-022-00864-9

Zhu, D. Q., Norman, I. J., & While, A. E. (2013). Nurses' self-efficacy and practices relating to weight management of adult patients: a path analysis. *International Journal of Behavioral Nutrition and Physical Activity*, *10*(1), 131. https://doi.org/10.1186/1479-5868-10-131

Appendices

Appendix 1. Databases, search queries and search results of the literature review

Database (date)	Search query	Years and limits	Results
PubMed (July 25th, 2024)	(pregnan* OR gravid* OR maternit* OR prenat* OR antenat* OR gestat* OR expectan* OR expecting mother* OR perinat* OR "post partum*" OR post-partum* OR postpartum* OR "Pregnancy/education"[Mesh] OR "Pregnancy/nursing"[Mesh] OR "Pregnancy/physiology"[Mesh] OR "Postpartum Period"[Mesh] OR "perinatal care"[MeSH] OR "Postnatal Care"[Mesh] OR "Prenatal Care"[Mesh] OR "Prenatal Education"[Mesh]) AND ("weight management*" OR weight-management* OR lifestyle* OR "Healthy Lifestyle"[Mesh] OR "Body Weight"[Mesh] OR "Gestational Weight Gain"[Mesh] OR "Obesity, Maternal"[Mesh]) AND (intervention* OR "health promotion*" OR "Health Education"[Mesh] OR "Maternal Behavior"[Mesh] OR "Internet-Based Intervention"[Mesh]) AND systematic [sb]	Publication years: 2019-2024 Systematic review	331
PubMed (January 2019)		Publication years: –2018 systematic review.	283
EBSCOhost: CINAHL, APA PsycArticles, APA PsycInfo, ERIC, MEDLINE, MLA Directory of Periodicals, MLA International Bibliography with Full Text, SocINDEX with Full Text (July 25th, 2024)	("pregnan*" OR "gravid*" OR "maternit*" OR "prenat*" OR "antenat*" OR "gestat*" OR "expectan*" OR "expecting mother*" OR (MH "Pregnancy+") OR (MH "Perinatal Care") OR (MH "Prenatal Care") OR (MH "Postnatal Period+") OR (MH "Postpartum Nursing")) AND (("weight management*" OR weight-management* OR lifestyle* OR (MH "Weight Control") OR (MH "Body Weight Changes+") OR (MH "Life Style+") OR (MH "Gestational Weight Gain") OR (MH "Obesity, Maternal") AND (intervention* OR "health promotion*" OR (MH "Health Education+") OR (MH "Maternal Behavior") OR (MH "Intervention Trials") OR (MH "Nursing Interventions") OR (MH "Internet-Based Intervention") AND ("systematic review*" OR "meta-analysis*" OR "review of literature*" OR "literature review*")	Publication years: 2019–2024	522
EBSCOhost: CINAHL, APA PsycArticles, APA PsycInfo, ERIC, MEDLINE, MLA Directory		Publication years: –2018	627

of Periodicals, MLA International Bibliography with Full Text, SocINDEX with Full Text January 2019			
Cochrane Library (July 25th, 2024)	(pregnan* OR gravid* OR maternit* OR prenat* OR antenat* OR gestat* OR expectan* OR expecting NEXT mother* OR perinat* OR post NEXT partum* OR post-partum* OR postpartum* OR OR perinat* OR MeSH descriptor: [Pregnancy] explode all trees) AND (weight NEXT management* OR weight-management* OR lifestyle* OR gestational NEXT weight NEXT gain* OR MeSH descriptor: [Weight Gain] explode all trees OR MeSH descriptor: [Body Weight] explode all trees AND (intervention* OR health NEXT promotion* OR health NEXT education OR MeSH descriptor: [Maternal Behavior] explode all trees OR MeSH descriptor: [Internet-Based Intervention] explode all trees)	Cochrane review. Publication: 01/01/2019–24/07/2024.	210
Cochrane Library (January 2019)		Cochrane review. Publication: –31/12/2018.	329
Web of Science (July 25th, 2024)	(pregnan* OR gravid* OR maternit* OR prenat* OR antenat* OR gestat* OR expectan* OR expecting mother* OR perinat* OR "post partum*" OR post-partum* OR postpartum*) AND ("weight management*" OR weight-management* OR lifestyle* OR "Healthy Lifestyle*" OR "Body Weight*" OR "Gestational Weight Gain*" OR "Maternal Obesity*") AND (intervention* OR "health promotion*" OR "Health Education*" OR "Maternal Behavior*" OR "Internet-Based Intervention*")	Review article. Publication years: 2019-2024. All open access. Language: English.	497
Web of Science (January 2019)		Review article. Publication years: -2018. All open access. Language: English	345
Scopus (July 25th, 2024)	(pregnan* OR gravid* OR maternit* OR prenat* OR antenat* OR gestat* OR expectan* OR expecting mother* OR perinat* OR "post partum*" OR post-partum* OR postpartum*) AND ("weight management*" OR weight-management* OR lifestyle* OR "Healthy Lifestyle*" OR "Body Weight*" OR "Gestational Weight Gain*" OR "Maternal Obesity*") AND (intervention* OR "health promotion*" OR "Health Education*" OR "Maternal Behavior*" OR "Internet-Based Intervention*")	Title, abstract and keywords. Publication years: 2019–2024. Review article. Language: English	316
Scopus (January 2019)		Title, abstract and keywords. Publication years: –2018. Review article. Language: English	355
MEDIC (July 25th, 2024)	(raskaus* OR pregnan* OR gravid* OR maternit* OR prenat* OR antenat* OR gestat* OR expectan* OR expecting mother* OR perinat* OR "post partum*" OR post-partum* OR postpartum*) AND (painonhallinta* OR elämäntapa* OR "elämän hallinta*" OR "weight management*" OR weight-management* OR lifestyle* OR "Healthy Lifestyle*" OR "Body Weight*" OR "Gestational Weight Gain*" OR "Maternal Obesity*") AND (käyttäytyminen* OR äitiyshuolto* OR intervention* OR "health promotion*" OR "Health Education*" OR "Maternal Behavior*" OR "Internet-Based Intervention*")	Publication years: 2019–2024.	21
MEDIC (January 2019)		Publication years: –2018.	32

Appendix 2. JBI Critical Appraisal Checklist for Systematic Reviews and Research Syntheses

Citation	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	Q11
Agha et al 2014	Y	Y	Y	Y	Y	Y	N	N	Y	Y	Y
Aung et al 2022	Y	N	N	Y	Y	Y	Y	Y	N/A	Y	N
Behnam et al 2022	Y	Y	Y	N	Y	Y	Y	Y	Y	Y	N
Bernardo et al 2023	Y	Y	Y	Y	Y	Y	N	Y	N/A	Y	Y
Brown et al 2012	N	Y	N	Y	Y	Y	Y	Y	N	N	Y
Choi et al 2018	Y	Y	Y	Y	Y*	Y	Y	N	Y	Y	Y
Dalrymple et al 2018	Y	N	Y	Y	Y	?	Y	Y	N/A	N	Y
Dodd et al 2010	Y	Y	N	Y	Y	?	Y	Y	N	N	Y
Du et al 2018	N	Y	N	Y	Y	Y	Y	Y	N	N	Y
Flannery et al 2019	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Flynn et al 2016	Y	Y	Y	Y	Y	Y	Y	Y	N/A	Y	Y
I-WIP 2017	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Kominiarek et al 2018	Y	Y	Y	Y	Y	Y	Y	N	N/A	N	Y
Kuang et al 2023	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Lamminpää et al 2018	Y	N	Y	Y	Y	Y	Y	Y	Y	Y	Y
Lau et al 2017	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
McGovern et al 2024	Y	Y	Y	Y	Y	Y	Y	Y	N/A	Y	Y
Nightingale et al 2023	Y	Y	Y	N	Y	Y	Y	Y	Y	N	Y
Shieh et al 2018	Y	Y	Y	N	Y	Y	Y	Y	N	Y	Y
Sui et al 2012	Y	Y	N	Y	Y	Y	N	Y	N	Y	N
Wu et al 2022	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Yeo et al 2016	Y	Y	N	Y	Y*		Y	Y	N	Y	Y
Yu et al 2024	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y

Items from the JBI Critical Appraisal Checklist for Systematic Reviews and Research Syntheses:1. Is the review question clearly and explicitly stated? 2. Were the inclusion criteria appropriate for the review question? 3. Was the search strategy appropriate? 4. Were the sources and resources used to search for studies adequate? 5. Were the criteria for appraising studies appropriate? 6. Was critical appraisal conducted by 2 or more reviewers independently? 7. Were there methods to minimize errors in data extraction? 8. Were the methods used to combine studies appropriate? 9. Was the likelihood of publication bias assessed? 10. Were recommendations for policy and/or practice supported by the reported data? 11. Were the specific directives for new research appropriate?

*No study was excluded based on the risk of bias

Appendix 3. The original studies of the literature review

Author(s), year	Title	Author of the review
Ainscough et al., 2020	Nutrition, Behavior Change and Physical Activity Outcomes From the PEARS RCT—An mHealth-Supported, Lifestyle Intervention Among Pregnant Women With Overweight and Obesity	Yu
Al Wattar et al, 2019	Mediterranean-style diet in pregnant women with metabolic risk factors (ESTEEM). A pragmatic multicentre randomised trial.	Behnam
Albright et al, 2014	Effectiveness of a 12-month randomized clinical trial to increase physical activity in multiethnic postpartum women: results from Hawaii's Na Mikimiki Project.	Lau
Altazan et al., 2019	The effect of antenatal dietary and lifestyle advice for women who are overweight or obese on emotional well-being: The LIMIT randomized trial.	Bernardo
Althuizen et al, 2012	The effect of a counselling intervention on weight changes during and after pregnancy: a randomised trial	Aung Yeo, Yu
Amamak et al, 2019	The impact of prenatal education based on the roy adaptation model on gestational hypertension, adaptation to pregnancy and pregnancy outcomes.	Nightingale
Artal et al, 2007	A lifestyle intervention of weight-gain restriction: diet and exercise in obese women with gestational diabetes mellitus.	Lamminpää
Asbee et al, 2009	Preventing excessive weight gain during pregnancy through dietary and lifestyle counseling: A randomized controlled trial.	Agha, Brown, Dodd, Yeo, Yu
Barakat et al, 2009	Resistance exercise training during pregnancy and newborn's birth size: a randomised controlled trial	Choi, Yeo, Sui
Barakat et al, 2016	Exercise during pregnancy protects against hypertension and macrosomia. Randomized clinical trial.	Behnam, Kuang
Barakat et al., 2019	Exercise during pregnancy has a preventative effect on excessive maternal weight gain and gestational diabetes. A randomized controlled trial.	Kuang
Basu et al, 2014	Eating for 1, Healthy and Active for 2; feasibility of delivering novel, compact training for midwives to build knowledge and confidence in giving nutrition, physical activity and weight management advice during pregnancy.	Kominiarek
Beauchesne et al., 2021	Effectiveness of multimodal nutrition interventions during pregnancy to achieve 2009 Institute of Medicine gestational weight gain guidelines: a systematic review and meta-analysis.	Yu
Bertz et al, 2012	A. Diet and exercise weight-loss trial in lactating overweight and obese women.	Dalrymble, Lau
Bertz et al, 2015	Sustainable weight loss among overweight and obese lactating women is achieved with an energy-reduced diet in line with dietary recommendations: results from the LEVA randomized controlled trial	Lau
Bisson et al, 2015	A 12-week exercise program for pregnant women with obesity to improve physical activity levels: an open randomised preliminary study	Du, Shieh
Bogaerts et al, 2013	Effects of lifestyle intervention in obese pregnant women on gestational weight gain and mental health: a randomized controlled trial	Aung, Wu, Nightingale, Behnam, Flynn, Yeo,

		Lamminpää, Shieh, Yu
Brankston et al, 2004	Resistance exercise decreases the need for insulin in overweight women with gestational diabetes.	Dodd, Sui
Brownfoot et al, 2016	Routine weighing to reduce excessive antenatal weight gain: a randomized controlled trial	Aung
Bruno et al, 2017	Adherence to a lifestyle programme in overweight/obese pregnant women and effect on gestational diabetes mellitus: a randomized controlled trial	Flannery, Behnam, Wu, Kuang
Buckingham-Schutt et al, 2019	The Behavioral Wellness in Pregnancy study: a randomized controlled trial of a multi-component intervention to promote appropriate weight gain.	Nightingale
Byrne et al, 2011	Changes in resting and walking energy expenditure and walking speed during pregnancy in obese women.	Yeo, Yu
Callaway et al, 2010	Prevention of gestational diabetes: feasibility issues for an exercise intervention in obese pregnant women.	Du, Flannery, Behnam, Sui
Chen, 2017	Clinical effectiveness analysis of comprehensive nursing measures for preventing gestational diabetes mellitus of women with overweight or obesity before pregnancy.	
Choi et al, 2016	mHealth Physical Activity Intervention: a randomized pilot study in physically inactive pregnant women.	Lau
Claesson et al, 2008	Weight gain restriction for obese pregnant women: a case-control intervention study	Agha
Claesson et al, 2014	Physical activity and psychological wellbeing in obese pregnant and postpartum women attending a weight-gain restriction programme.	Aung
Colleran et al, 2012	Use of mypyramid menu planner for moms in a weight-loss intervention during lactation.	Dalrymble, Lau
Craigie et al, 2011	Supporting postpartum weight loss in women living in deprived communities: design implications for a randomized control trial.	Choi, Dalrymble
Dahl et al., 2020	Healthy Motivations for Moms-To-Be (Healthy MoM2B) Study: A mobile health intervention targeting gestational weight gain among US women.	Yu
Daley et al, 2015	Feasibility and acceptability of regular weighing, setting weight gain limits and providing feedback by community midwives to prevent excess weight gain during pregnancy: randomised controlled trial and qualitative study.	Kominiarek
Daley et al, 2019	Effectiveness of a behavioural intervention involving regular weighing and feedback by community midwives within routine antenatal care to prevent excessive gestational weight gain: POPS2 randomised controlled trial.	Nightingale
Daly et al, 2017	A medically supervised pregnancy exercise intervention in obese women: a randomized controlled trial.	Du, Behnam, Kuang
Darvall et al., 2022	A Pedometer-Guided Physical Activity Intervention for Obese Pregnant Women (the Fit MUM Study): Randomized Feasibility Study	Yu
Davis et al, 2012	Addressing obesity in pregnancy: the design and feasibility of an innovative intervention in NSW, Australia.	Kominiarek
Dekker et al, 2015	Exercise in pregnancy does not alter gestational weight gain, MCP-1 or leptin in obese women.	Du, Yeo, Shieh, Yu
DeSequiera et al., 2019	Culturally tailored resources for south Asian immigrant women with gestational diabetes: do they work and What's missing? A Qualitative Study.	McGovern
Ding et al, 2021	WeChat-assisted dietary and exercise intervention for prevention of gestational diabetes mellitus in	Wu

	overweight/obese pregnant women: A two-arm randomized clinical trial.	
Dodd et al, 2014	Antenatal Dietary and Lifestyle Interventions for Women Who are Overweight or Obese: Outcomes from the LIMIT Randomised Trial. Current Nutrition Reports	Aung, Yeo, Flannery, Behnam, Flynn, Shieh, Yu, Kuang
Dodd et al., 2016	The effect of antenatal dietary and lifestyle advice for women who are overweight or obese on emotional well-being: The LIMIT randomized trial.	Bernardo
Dodd et al, 2019	Effect of metformin in addition to dietary and lifestyle advice for pregnant women who are overweight or obese: the GRoW randomised, double-blind, placebo controlled trial	Aung
Downs et al., 2021	Adaptive, behavioral intervention impact on weight gain, physical activity, energy intake, and motivational determinants: results of a feasibility trial in pregnant women with overweight/obesity.	Yu
Edwards et al., 2021	How do women with a history of gestational diabetes mellitus use mHealth during and after pregnancy? Qualitative exploration of women's views and experiences.	McGovern
Eslami et al, 2018	The Effect of a Lifestyle-Based Training Package on Weight Gain and Frequency of Gestational Diabetes in Obese and Overweight Pregnant Females	Behnam
Ekezie et al., 2021	Experiences of using a digital type 2 diabetes prevention application designed to support women with previous gestational diabetes	McGovern
Falciglia et al, 2017	A theory-based dietary intervention for overweight, postpartum mothers and their children improves maternal vegetable intake	Dalrymble
Ferrara et al, 2011	A pregnancy and postpartum lifestyle intervention in women with gestational diabetes mellitus reduces diabetes risk factors: A feasibility randomized control trial.	Dalrymble
Ferrara et al, 2020	A telehealth lifestyle intervention to reduce excess gestational weight gain in pregnant women with overweight or obesity (GLOW): a randomised, parallel-group, controlled trial	Nightingale, Yu
Fjeldsoe et al, 2010	MobileMums: a randomized controlled trial of an SMS-based physical activity intervention.	Lau
Garmendia et al., 2021	The effects of a combined intervention (docosahexaenoic acid supplementation and home-based dietary counseling) on metabolic control in obese and overweight pregnant women: the MIGHT study.	Yu
Garnaes et al, 2016	Effect of supervised exercise training during pregnancy on neonatal and maternal outcomes among overweight and obese women. Secondary analyses of the ETIP trial: a randomised controlled trial	Aung, Du, Flannery, Behnam, Yeo, Shieh, Yu, Kuang
Garnaes et al, 2018	Exercise training during pregnancy reduces circulating insulin levels in overweight/obese women postpartum: secondary analysis of a randomised controlled trial (the ETIP trial)	Yu
Garnaes et al, 2019	Effects of supervised exercise training during pregnancy on psychological well-being among overweight and obese women: Secondary analyses of the ETIP-trial, a randomised controlled trial.	Bernardo
Gesell et al., 2015	Feasibility and Initial Efficacy Evaluation of a Community-Based Cognitive-Behavioral Lifestyle Intervention to Prevent Excessive Weight Gain During Pregnancy in Latina Women.	Yu

Gilmore et al, 2017	Personalized mobile health intervention for health and weight loss in postpartum women receiving women, infants, and children benefit: A randomized controlled pilot study.	Dalrymble
Given et al., 2015	Tele-mum: a feasibility study for a randomized controlled trial exploring the potential for telemedicine in the diabetes care of those with gestational diabetes.	McGovern
Gonzales-Plaza et al., 2022	Effectiveness of a Step Counter Smartband and Midwife Counseling Intervention on Gestational Weight Gain and Physical Activity in Pregnant Women With Obesity (Pas and Pes Study): Randomized Controlled Trial.	Yu
Graham et al., 2014	he Theory, Development, and Implementation of an e-Intervention to Prevent Excessive Gestational Weight Gain: e-Moms Roc.	Yu
Greene et al., 2021	Acceptability of the pregnancy, exercise, and nutrition research study with smartphone app support (PEARS) and the use of Mobile health in a mixed lifestyle intervention by pregnant obese and overweight women: secondary analysis of a randomized controlled trial.	McGovern
Guelfi et al., 2016	Regular exercise to prevent the recurrence of gestational diabetes mellitus: a randomized controlled trial.	Kuang
Guelinckx et al, 2009	Effect of lifestyle intervention on dietary habits, physical activity, and gestational weight gain in obese pregnant women: a randomised controlled trial.	Aung, Agha, Brown, Choi, Dodd, Flannery, Flynn, Yeo, Lamminpää, Shieh, Yu
Guo et al., 2020	Effect of walking exercise program on pregnancy outcome of obese pregnant women	Kuang
Haakstad et al, 2011	Effect of regular exercise on prevention of excessive weight gain in pregnancy: A randomised controlled trial.	Agha
Haby et al, 2015	Mighty Mums – An antenatal health care intervention can reduce gestational weight gain in women with obesity.	Aung, Lamminpää
Haby et al, 2018	Mighty Mums – a lifestyle intervention at primary care level reduces gestation weight gain in women with obesity.	Aung
Hajian et al., 2020	The effectiveness of healthy lifestyle interventions on weight gain in overweight pregnant women: A cluster-randomized controlled trial.	Yu
Harden et al, 2014	Group-based lifestyle sessions for gestational weight gain management: a mixed method approach.	Nightingale, Yeo, Yu
Harreiter et al., 2019	Nutritional Lifestyle Intervention in Obese Pregnant Women, Including Lower Carbohydrate Intake, Is Associated With Increased Maternal Free Fatty Acids, 3-β-Hydroxybutyrate, and Fasting Glucose Concentrations: A Secondary Factorial Analysis of the European Multicenter, Randomized Controlled DALI Lifestyle Intervention Trial.	Yu
Harrison et al, 2013	Optimizing healthy gestational weight gain in women at high risk of gestational diabetes: a randomized controlled trial	Nightingale, Behnam, Flynn, Yeo, Lamminpää, Lau, Yu
Harrison et al, 2014	How effective is self-weighing in the setting of a lifestyle intervention to reduce gestational weight gain and postpartum weight retention?	Aung, Shieh, Lau
Harrison et al., 2017	Acceptability of virtual prenatal visits for women with gestational diabetes.	McGovern

Harvey et al., 2020	'Be kind to yourself –because you're doing fine': using self-determination theory to explore the health-related experiences of primiparous women participating in a co-active life coaching intervention.	McGovern
Hawkins et al, 2015	A pregnancy lifestyle intervention to prevent gestational diabetes risk factors in overweight Hispanic women: a feasibility randomized controlled trial.	Flannery, Flynn, Yeo, Lamminpää, Shieh, Yu
Herring et al, 2014	Using technology to promote postpartum weight loss in urban, low-income mothers: A pilot randomized controlled trial.	Dalrymble, Lau
Herring et al 2016	Preventing excessive gestational weight gain among African American women: a randomised clinical trial.	Aung, Yeo, Lau, Nightingale, Yu, Kuang
Herring et al, 2017	Intervening during and after pregnancy to prevent weight retention among african american women.	Dalrymble
Heslehurst et al, 2015	An evaluation of the implementation of maternal obesity pathways of care: a mixed methods study with data integration.	Kominiarek
Horn et al., 2023	Postpartum women's experiences in a randomized controlled trial of a web-based lifestyle intervention following gestational diabetes: a qualitative study.	McGovern
Hua et al., 2016	Effect of walking exercise on the pregnancy outcome of overweight pregnant women	Kuang
Huang et al, 2009	A diet and physical activity intervention for preventing weight retention among taiwanese childbearing women: A randomised controlled trial.	Brown
Hui et al, 2006	Community-based exercise and dietary intervention during pregnancy: A pilot study	Agha, Yeo, Lau, Yu
Huseinovic et al, 2016	Effectiveness of a weight loss intervention in postpartum women: Results from a randomized controlled trial in primary health care	Dalrymble
Ilmonen et al, 2011	Impact of dietary counselling and probiotic intervention on maternal anthropometric measurements during and after pregnancy: A randomized placebo-controlled trial.	Agha
Jackson et al, 2011	Improving diet and exercise in pregnancy with Video Doctor counseling: A randomized trial.	Agha, Lau, Nightingale
Jeffries et al, 2009	Reducing excessive weight gain in pregnancy: a randomised controlled trial.	Agha, Yeo, Yu
Jones et al 2014	Identifying postpartum intervention approaches to reduce incidence of type 2 diabetes and cardiovascular disease in American Indian women with previous gestational diabetes	McGovern
Kemp et al., 2024	Mothers' experiences of a lifestyle intervention for weight reduction 12 months after gestational diabetes mellitus: qualitative findings from the PAIGE2 study.	McGovern
Kennelly et al, 2018	Pregnancy exercise and nutrition with smartphone application support: a randomized controlled trial.	Flannery, Nightingale, Behnam, Yu, Kuang
Killeen et al 2022	The Edmonton Obesity Staging System and pregnancy outcomes in women with overweight or obesity: A secondary analysis of a randomized controlled trial.	Bernardo
Kinnunen et al, 2007	Preventing excessive weight gain during pregnancy – a controlled trial in primary health care.	Agha
Kinnunen et al, 2008	Feasibility of a controlled trial aiming to prevent excessive pregnancy-related weight gain in primary health care.	Kominiarek

Koivusalo et al, 2016	Gestational diabetes mellitus can be prevented by lifestyle intervention: the Finnish gestational diabetes prevention study (RADIEL): a randomized controlled trial.	Flannery, Yeo, Yu
Koleilat et al., 2020	Postpartum Weight-Loss Tracker to Guide Low-Income Postpartum Women on their Weight-Loss Journey.	McGovern
Kong et al, 2014 13?	A pilot walking program promotes moderate-intensity physical activity during pregnancy	Du, Flannery, Yeo, Shieh
Krebs et al 2022	Effectiveness of a Brief Lifestyle Intervention in the Prenatal Care Setting to Prevent Excessive Gestational Weight Gain and Improve Maternal and Infant Health Outcomes.	Yu
Krukowski et al, 2017	A Behavioural Intervention to Reduce Excessive Gestational Weight Gain	Aung
Ku et al., 2022	Developing a lifestyle intervention program for overweight or obese preconception, pregnant and post-partum women using qualitative methods.	McGovern
Kytö et al., 2022	Behavior change app for selfmanagement of gestational diabetes: design and evaluation of desirable features.	McGovern
Lee et al., 2023	“Help me fight my constant battle”: a focus group study of overweight and obese women's mHealth app experiences to manage gestational weight gain.	McGovern
Lim et al., 2017	Comparing a telephone- and a group-delivered diabetes prevention program: characteristics of engaged and non-engaged postpartum mothers with a history of gestational diabetes	McGovern
Lindberg et al, 2014	Improving gestational weight gain counseling through meaningful use of an electronic medical record	Kominiarek
Lindhardt et al, 2014	Training in motivational interviewing in obstetrics: a quantitative analytical tool.	Kominiarek
Lindholm et al, 2010	Weight control programme for obese pregnant women.	Aung
Liu et al, 2021	A Behavioral Lifestyle intervention to limit gestational weight gain in pregnant women with overweight and obesity	Nightingale, Yu
Luoto et al., 2011	Primary prevention of gestational diabetes mellitus and large-for-gestational-age newborns by lifestyle counseling: a cluster-randomized controlled trial.	Yu
Lovelady et al, 2000	The effect of weight loss in overweight, lactating women on the growth of their infants.	Choi, Dalrymble
Magee et al, 1990	Metabolic effects of 1200-kcal diet in obese pregnant women with gestational diabetes	Dodd
Markovic et al, 2016	Randomized controlled trial investigating the effects of a low-glycemic index diet on pregnancy outcomes in women at high risk of gestational diabetes mellitus: the GI Baby 3 study.	Lamminpää
McCarthy et al, 2016	Self-weighing and simple dietary advice for overweight and obese pregnant women to reduce obstetric complications without impact on quality of life: a randomised controlled trial.	Aung, Wu, Behnam, Yeo, Shieh, Yu
McDonald et al., 2022	Influence of prenatal exercise on the relationship between maternal overweight and obesity and select delivery outcomes.	Kuang
McGiveron et al, 2015	Limiting antenatal weight gain improves maternal health outcomes in severely obese pregnant women: findings of a pragmatic evaluation of a midwife-led intervention.	Aung, Lamminpää
McNitt et al., 2022	Underreporting of Energy Intake Increases over Pregnancy: An Intensive Longitudinal Study of Women with Overweight and Obesity.	Yu

Nascimento et al, 2011	The effect of an antenatal physical exercise program on maternal/perinatal outcomes and quality of life in overweight and obese pregnant women: a randomized clinical trial.	Choi, Du, Flannery, Yeo, Shieh, Sui, Yu, Kuang
Nicholson et al., 2016	The gestational diabetes management system (GooDMomS): development, feasibility and lessons learned from a patient-informed, web-based pregnancy and postpartum lifestyle intervention.	McGovern
Nicklas et al., 2011	Identifying postpartum intervention approaches to prevent type 2 diabetes in women with a history of gestational diabetes.	McGovern
Nicklas et al, 2014	A web-based lifestyle intervention for women with recent gestational diabetes mellitus: A randomized controlled trial	Dalrymble
Nobles et al, 2016, 15?	The Effect of an Exercise Intervention on Gestational Weight Gain.	Behnam
Okesene-Gafa et al, 2019	Effect of antenatal dietary interventions in maternal obesity on pregnancy weight-gain and birthweight: Healthy Mums and Babies (HUMBA) randomized trial.	Aung, Wu
Olson et al, 2018	The effectiveness of an online intervention in preventing excessive gestational weight gain: The e-moms roc randomized controlled trial.	Nightingale, Yu
Ong et al, 2009	Supervised home-based exercise may attenuate the decline of glucose tolerance in obese pregnant women.	Choi, Du, Flannery, Yeo, Sui, Yu
Oostdam et al, 2012	No effect of the FitFor2 exercise programme on blood glucose, insulin sensitivity, and birthweight in pregnant women who were overweight and at risk for gestational diabetes: results of a randomised controlled trial.	Du, Flannery, Behnam, Kuang
O´Reilly et al., 2019	Health-e mums: evaluating a smartphone app design for diabetes prevention in women with previous gestational diabetes.	McGovern
Osmundson et al, 2016	Early Screening and Treatment of Women with Prediabetes.	Behnam
Østbye et al, 2009	Active mothers postpartum: a randomized controlled weight-loss intervention trial	Choi, Dalrymble
Peccei et al, 2017	Intensive Prenatal Nutrition Counselling in a Community Health Setting: A Randomised Controlled Trial.	Aung, Dalrymble
Petrella et al, 2014	Gestational weight gain in overweight and obese women enrolled in a healthy lifestyle and eating habits program.	Wu, Behnam, Flynn, Yeo, Lamminpää, Shieh, Yu
Phelan et al, 2011	Randomized trial of a behavioural intervention to prevent excessive gestational weight gain: The Fit for delivery study.	Agha, Brown, Choi, Nightingale, Yeo, Lau, Yu
Phelan et al, 2013	Does behavioral intervention in pregnancy reduce postpartum weight retention? Twelve-month outcomes of the fit for delivery randomized trial	Dalrymble, Lau
Pollak et al, 2014	Weight-related SMS texts promoting appropriate pregnancy weight gain: a pilot study.	Lau, Yu
Polley et al, 2002	Randomized controlled trial to prevent excessive weight gain in pregnant women.	Agha, Brown, Choi, Dodd, Nightingale, Yu

Poston et al, 2013	Developing a complex intervention for diet and activity behaviour change in obese pregnant women (the UPBEAT trial); assessment of behavioural change and process evaluation in a pilot randomised controlled trial.	Flynn, Shieh, Bernardo, Kuang
Poston et al, 2015	Effect of a behavioural intervention in obese pregnant women (the UPBEAT study): a multicentre, randomised controlled trial.	Flannery, Nightingale, Wu, Behnam, Lamminpää, Lau, Yu, Kuang
Quinlivan et al, 2011	A randomised trial of a fourstep multidisciplinary approach to the antenatal care of obese pregnant women.	Aung, Behnam, Flynn, Yeo, Lamminpää, Shieh, Yu
Rae et al, 2000	A randomised controlled trial of dietary energy restriction in the manage- ment of obese women with gestational diabetes.	Dodd
Rasekaba et al., 2021	Women, clinician and IT staff perspectives on telehealth for enhanced gestational diabetes mellitus management in an Australian rural/regional setting.	McGovern
Rauh et al, 2013	Safety and efficacy of a lifestyle intervention for pregnant women to prevent excessive maternal weight gain: a cluster-randomized controlled trial.	Nightingale
Redman et al., 2017	Effectiveness of SmartMoms, a Novel eHealth Intervention for Management of Gestational Weight Gain: Randomized Controlled Pilot Trial.	Yu
Renault et al, 2014	The Treatment of Obese Pregnant Women (TOP) study: a randomized controlled trial of the effect of physical activity intervention assessed by pedometer with or without dietary intervention in obese pregnant women	Aung, Du, Flannery, Wu, Behnam, Flynn, Yeo, Lamminpää, Shieh, Yu, Kuang
Rhodes et al, 2010	Effects of a low-glycemic load diet in overweight and obese pregnant women a pilot randomized controlled trial.	Yeo, Shieh, Yu
Ronnberg et al, 2015	Intervention during pregnancy to reduce excessive gestational weight gain – a randomised controlled trial	Aung
Ruben et al., 2011	Exercise during pregnancy improves maternal glucose screen at 24–28 weeks: a randomised controlled trial.	Yu
Ruiz et al, 2013	Supervised exercise-based intervention to prevent excessive gestational weight gain: a randomized controlled trial.	Yeo, Yu
Sandborg et al., 2021	Effectiveness of a Smartphone App to Promote Healthy Weight Gain, Diet, and Physical Activity During Pregnancy (HealthyMoms): Randomized Controlled Trial.	Yu
Sandborg et al., 2022	The effects of a lifestyle intervention (the HealthyMoms app) during pregnancy on infant body composition: Secondary outcome analysis from a randomized controlled trial.	Yu
Santos et al, 2005	Aerobic exercise and submaximal functional capacity in overweight pregnant women	Dodd, Flannery, Yeo, Sui, Yu
Santorelli et al., 2023	Effectiveness of a minimally processed food-based nutritional counselling intervention on weight gain in overweight pregnant women: a randomized controlled trial.	Yu
Seneviratne et al, 2016, 15?	Effects of antenatal exercise in overweight and obese pregnant women on maternal and perinatal outcomes: a randomised controlled trial.	Du, Flannery, Yeo, Shieh, Yu, Bernardo

Seward et al., 2018	Supporting healthful lifestyles during pregnancy: a health coach intervention pilot study	McGovern
Shang et al., 2021	Chinese women's attitudes towards postpartum interventions to prevent type 2 diabetes after gestational diabetes: a semi-structured qualitative study	McGovern
Simmons et al, 2017	Effect of physical activity and/or healthy eating on GDM risk: the DALI lifestyle study.	Du, Nightingale, Wu, Behnam, Shieh
Skar et al., 2018	Women's experiences with using a smartphone app (the pregnant+ app) to manage gestational diabetes mellitus in a randomised controlled trial.	McGovern
Skouteris et al, 2016	Health coaching to prevent excessive gestational weight gain: A randomized-controlled trial.	Nightingale
Smith et al, 2014	The Blossom Project Online: use of a behaviorally-based website to promote physical activity and prevent excessive gestational weight gain in previously sedentary pregnant women.	Lau
Smith et al, 2016	Web-based behavioral intervention increases maternal exercise but does not prevent excessive gestational weight gain in previously sedentary women	Nightingale, Yu
Soltani et al., 2012	Women's and midwives' perspectives on the design of a text messaging support for maternal obesity services: an exploratory study.	McGovern
Surendran et al., 2021	Women's Usage Behavior and Perceived Usefulness with Using a Mobile Health Application for Gestational Diabetes Mellitus: Mixed-Methods Study.	McGovern
Szmeja et al, 2014	Use of a DVD to provide dietary and lifestyle information to pregnant women who are overweight or obese: a nested randomised trial	Flannery, Shieh
Thomas et al., 2022	A Web-Based mHealth Intervention With Telephone Support to Increase Physical Activity Among Pregnant Patients With Overweight or Obesity: Feasibility Randomized Controlled Trial	Yu, McGovern
Thomson et al, 2016	Gestational Weight Gain.	Behnam
Thornton et al, 2009	Perinatal outcomes in nutritionally monitored obese pregnant women: a randomized clinical trial	Agha, Dodd, Behnam, Flynn, Yeo, Shieh, Yu
Tyldesley-Marshall et al., 2021	The experiences of postnatal women and healthcare professionals of a brief weight management intervention embedded within the national child immunisation programme.	McGovern
Van Horn et al, 2018 or	Dietary approaches to stop hypertension diet and activity to limit gestational weight: maternal offspring Metabolics family intervention trial, a technology enhanced randomized trial	Flannery, Behnam, Yu
Vesco et al, 2014	Efficacy of a group-based dietary intervention for limiting gestational weight gain among obese women: a randomized trial.	Nightingale, Behnam, Flynn, Yeo, Lamminpää, Shieh, Yu
Vesco et al, 2016	One-year postpartum outcomes following a weight management intervention in pregnant women with obesity	Dalrymble
Vinter et al, 2011	The LiP (Lifestyle in Pregnancy) Study: a randomized controlled trial of lifestyle intervention in 360 obese pregnant women.	Choi, Yeo, Flannery, Wu, Flynn,

		Lamminpää, Shieh, Yu
Vinter et al, 2014	Postpartum weight retention and breastfeeding among obese women from the randomized controlled lifestyle in pregnancy	Dalrymble, Behnam
Walker et al, 2011	Ethnic-specific weight-loss interventions for low-income postpartum women: findings and lessons	Choi
Wang et al, 2017	A randomized clinical trial of exercise during pregnancy to prevent gestational diabetes mellitus and improve pregnancy outcome in overweight and obese pregnant women.	Du, Wu, Behnam, Kuang
Waring et al., 2022	Feedback on Instagram posts for a gestational weight gain intervention.	McGovern
Weisman et al, 2011	Improving Women's Preconceptional Health: Long-Term Effects of the Strong Healthy Women Behaviour Change Intervention in the Central Pennsylvania Women's Health Study.	Agha
Wilkinson et al, 2015	Trial for reducing weight retention in new mums: A randomised controlled trial evaluating a low intensity, postpartum weight management programme.	Dalrymble
Wilkinson et al, 2023	Informing a healthy eating and physical activity program to decrease postnatal weight retention: what are women experiencing and what type of program do they want?	McGovern
Wiltheiss et al, 2013	Diet quality and weight change among overweight and obese postpartum women enrolled in a behavioral intervention program	Dalrymple
Wolff et al, 2008	A randomized trial of the effects of dietary counseling on gestational weight gain and glucose metabolism in obese pregnant women.	Agha, Dodd, Wu, Flynn, Yeo, Lamminpää, Shieh, Yu
Zhang et al, 2015	Comprehensive effect assessment of medical nutrition guidance during pregnancy towards the health of mothers and children.	Behnam
Zhang et al, 2019	Effectiveness of Low Glycemic Index Diet Consultations Through a Diet Glycemic Assessment App Tool on Maternal and Neonatal Insulin Resistance: A Randomized Controlled Trial.	Wu, Behnam
Yee et al., 2020	Patient and provider perspectives on a novel Mobile health intervention for low-income pregnant women with gestational or type 2 diabetes mellitus.	McGovern

Appendix 4. Characteristics of the included systematic reviews

Author(s), year **JBI score**	**Aim of the review**	**Participants (P), n = total number included in review (o = total number for overweight/obese subgroup)]**	**Intervention (I)** **Control (C)** **Duration**	**Outcomes of the review (O)**	**Included studies, n [number for overweight/obese subgroup]** **Country** **Years of publications**	**Theoretical/behavioral frameworks/techniques utilized**
Agha et al., 2014 JBI 9/11.	To assess the efficacy of behavioral interventions for weight-management during pregnancy in women with overweight, obesity and morbid obesity.	n = 3416, (o = 631) Women of child-bearing age planning to get pregnant (n = 692), or/and those who were already pregnant (n = 2734).	*Intervention:* Behavioral interventions for weight-management categorized: passive or pro-active (including diet, PA, motivational talks or feedback/and or weight monioring *Control:* Standard maternity care *Duration:* from 8 gestational week to 24 months postpartum *Recruitment:* from 8 to 28 gestational weeks	GWG, PPWL, PPWR Gestation week of delivery, infant birth weight	15 (13 RCTs, 1 CCT, 1 CBA) [2] *Countries:* USA, Canada, Australia, Finland, Sweden, Denmark, Norway and Belgium. *Years:* N/A	Behavioral interventions for weight-management categorized: passive or pro-active (including diet, PA, motivational talks or feedback/and or weight monitoring
Aung et al., 2022 JBI 7/11	To examine the recent evidence of interventions in limiting GWG in pregnant women who are overweight or obese.	n = U The sample size of overweight and obese pregnant women ranged from 27 to 2212 participants.	*Intervention:* Lifestyle modifications, medications, and multidisciplinary team-based approaches including midwifery and psycho-behavioral input. *Control:* Routine antenatal care *Duration*: N/A *Recruitment:* N/A	GWG	21 (13 RCTs, 4 prospective intervention studies, 3 pilot studies and 1 retrospective study) *Countries:* Australia, New Zealand, Europe, USA and UK. *Years:* 2010–2019.	Social cognitive theory to emphasize self-efficacy, psycho-behavioral components: motivational interviewing, self-monitoring, goal setting.

Behnam et al., 2022 JBI 10/11	To perform a systematic review and different meta-analyses investigating lifestyle interventions specifically designed to limit adverse effects of obesity during pregnancy.	n = 11416, (o = 11416) Pregnant women who were classified as overweight or obese	*Intervention:* PA, diet and combined interventions, behavioral therapy. *Control:* Undefined *Duration:* range between 1 session and 30 weeks *Recruitment:* From 8 to 20 gestational weeks	GWG, HPD, GDM Maternal and infant outcomes	28 [23 RCTs had data on GWG] *Countries:* USA, Europe, Australia, China and Iran. *Years:* 2008–2021.	Behavioral therapy, goal setting, group sessions, increasing self-efficacy, controls- and social cognitive theory, motivational interviewing.
Bernardo et al., 2023 JBI 9/11	To conduct a systematic review on the effects of PA on the quality of life of pregnant women with overweight or obesity	N = 2684 (o = 2684) overweight or obese pregnant women	*Intervention:* Nutritional, PA and lifestyle counselling *Control:* standard care *Duration:* N/A *Recruitment;* From 10 to 20 gwks	Quality of life, GWG	6 *Countries:* USA, Europe, Australia, New Zealand *Years:* 2013–2022.	Behavioral counselling
Brown et al., 2012 JBI 7/11	To explore the use of goal setting within healthy lifestyle interventions for the prevention of excess GWG.	n = 971, (o = 66) Healthy pregnant women	*Intervention:* Interventions using goalsetting alongside modification to diet and physical activity based interventions (alone or combination) *Control:* Standard antenatal care *Duration: range between 23 weeks and 49 weeks* *Recruitment:* From 6 to 20 gwks	GWG Psycho-behavioral outcomes (maternal self-efficacy)	5 [1] *Countries:* N/A *Years*: 2002–2011.	Goal setting: purpose goals, target goals, performance feedback, weight monitoring, self-monitoring of diet and PA.
Choi et al., 2013 JBI 9/11	To systematically review and investigate the effectiveness of physical activity alone interventions as well as PA plus diet interventions in managing weight change among OW/OB women during pregnancy as well as postpartum.	n = 721, (o = 721) Overweight or obese pregnant women n = 547, (o = 547) Overweight or obese post-partum women	*Intervention:* Dietary, PA and lifestyle interventions. *Control:* Routine care. *Duration: range between 10 weeks and 9 months* *Recruitment*: from 10 to 18 gestational weeks	GWG, PPWR	11 (7 studies with pregnant women and 4 studies with postpartum women) *Countries:* Australia, Brazil, Belgium, Denmark, Spain, USA and UK. *Years:* 2000–2011.	Health behaviors perceived stress, self-efficacy, feedback on weight, self-monitoring, food records.

Dalrymple et al., 2018 JBI 7/11	To systematically evaluate the effectiveness of lifestyle interventions initiated during the antenatal and/or postnatal period in overweight or obese pregnant women to manage postpartum weight	N = 2559, (o = U) Overweight and obese pregnant or postpartum women.	*Intervention:* Diet or diet and PA initiated during pregnancy, postpartum or both. *Control:* Standard care *Duration:* range between 10 weeks and 12 months *Recruitment: from 10 gestational weeks to 7 months postpartum*	Maternal postpartum weight or body composition data >3 months and <2 years after delivery	18, pregnancy only (n = 3), pregnancy and postpartum (n = 3) postpartum only (n = 12). *Countries:* Denmark, Sweden, Australia, USA and UK. *Years:* 2000-2017.	Goal setting, behavior change strategies.
Dodd et al., 2010 JBI 8/11	To evaluate the benefits and harms associated with the provision of antenatal dietary and/or lifestyle intervention for pregnant women who are overweight or obese.	N = 743, o = 743) Pregnant women who were overweight or obese.	*Intervention:* Antenatal dietary and/or lifestyle advice or intervention *Control:* Standard care *Duration*: N/A *Recruitment:* from 10 to 32 gestational weeks	GWG Infant birth weight	9 [4] *Countries:* Denmark, Belgium Australia, USA and Brazil. *Years*: 1990-2009.	Behavioral weight management.
Du et al., 2018 JBI 7/11	To examine whether PA alone during pregnancy among women with overweight or obesity could improve maternal and infant outcomes.	N = 1439, (o = 1172) Overweight or obese pregnant women.	*Intervention:* Physical exercise without dietary interventions during pregnancy. *Control:* Standard antenatal care *Duration:* range between 13 weeks and 34 weeks *Recruitment:* N/A	GWG, GDM	13 [12] *Countries:* Australia, New Zealand, Norway, Denmark, Canada, Netherlands, USA, Ireland, China and Brazil. *Years*:2009–2017	Self-monitoring, goal setting.
Flannery et al., 2019 JBI 11/11	To identify and summarize the evidence for the effectiveness of PA interventions for pregnant women with overweight and obesity on PA levels and identify which BCTs were most frequently used in these interventions.	N = 7822, (o = 7822) Pregnant women with overweight and obesity	*Intervention:* PA interventions *Control:* Standard antenatal care *Duration:* range between 8 and 24 weeks *Recruitment:* N/A	GWG, GDM, Infant births weight PA levels, BCTs which were most effective in improving PA levels	19 (13 suitable for meta-analysis) [12] *Countries:* USA, UK, Ireland, Netherlands, Brazil, New Zealand, Australia, Italy, Finland, Denmark, Belgium and Norway. *Years:* 2005–2018	Health decision making, behavioral modification, the transtheoretical model, social cognitive theory, control theory.

Flynn et al., 2016 JBI 10/11	To comprehensively evaluate the published literature on diet and lifestyle interventions aimed at reducing obesity in pregnancy in order to identify effective approaches.	N = 4276, (o = 4276) Overweight or obese pregnant women	*Intervention:* Diet and/or lifestyle *Control:* No intervention *Duration:* from 12 to 30 weeks, range between 2 and 16 contacts. *Recruitment:* from 10 to 28 weeks.	GWG, GDM, dietary and PA outcomes Maternal and infant outcomes	13 *Countries:* Australia, Belgium, Denmark, Italy, USA and UK. *Years*: 2008–2015	Goal setting, feedback.
The International Weight Management in Pregnancy Collaborative Group, I-WIP, 2017 Rogozińska et al., 2017 JBI 11/11	To assess the effects of diet and PA-based interventions, primarily on gestational weight gain and on maternal and offspring composite outcomes.	N = 9320, individual participant data for GWG outcome (o = 5909) Pregnant women from all BMI categories.	*Intervention:* Diet, PA and mixed intervention. *Control:* No intervention or routine antenatal care *Duration:* N/A *Recruitment:* N/A	GWG maternal and/or neonatal outcomes	106 [33 had individual participant data on GWG] *Countries:* Europe, North America, South America, Australia, Egypt and Iran. *Years:* from 1990 to 2017	Behavior modifying techniques.
Kominiarek et al., 2018 JBI 8/11	To perform a systematic review of the literature to identify studies that specifically targeted the obstetric provider in interventions that focused either on the perinatal management of obesity and/or gestational weight gain.	N = 335 (6 studies, 1 didn´t provide sample size) Prenatal care providers	*Intervention:* Interventions that focused either on the perinatal management of obesity and/or gestational weight gain. *Control:* Standard care *Duration*: N/A *Recruitment:* N/A	Changing obstetric provider behaviors in managing perinatal obesity and/or gestational weight gain	7 (2 focused on the management of obesity, three focused on GWG, and two focused on both topics) *Countries*: UK, USA, Australia, Denmark, and Finland. *Years:* 2008–2015	Motivational interviewing, Specific counseling techniques

Kuang et al 2023 JBI /11	To explore how exercise therapy influences pregnancy complications and outcomes in obese or overweight women	N = 6812 (o = N = 3448 in the intervention group and N = 3364 in the control group included 3364 cases.	*Intervention:* Exercise therapy *Control:* standard care *Duration:* N/A *Recruitment:* N/A	GWG maternal and/or neonatal outcomes	22 (15 studies reported effects on GWG) *Countries*: China, UK, Norway, USA, Spain, Italy, Denmark, New Zealand, Australia, Ireland, Brazil and Netherlands. *Years*: 2011–2022.	
Lamminpää et al., 2018 JBI 10/11	To describe the efficacy of dietary interventions—targeted for overweight and obese pregnant women—that limit GWG and prevent GDM.	N = N/A, (o = range from 50 to 1555) Overweight or obese pregnant women	*Intervention:* Dietary intervention or a dietary component *Control: N/A* No intervention or intervention with a differing content *Duration:* range between 12 and 20 weeks. *Recruitment:* < 20 gestational weeks.	GWG GDM	15 (12 RCTs, 3 CTs) *Countries:* Australia, UK, Denmark, Sweden Belgium, Italy and USA. *Years:* 2007–2016	N/A
Lau et al., 2017 JBI 11/11	To synthesize the best evidence to assess the effectiveness of e-based lifestyle interventions in improving maternal and neonatal outcomes among women with overweight or obesity during perinatal period.	N = 3169, (o = 3169) Women with overweight or obesity during the perinatal period (starting from pregnancy to 1 year postpartum).	*Intervention:* E-based lifestyle interventions comprising at least one component of dietary control, PA and weight management. *Control:* A minimal intervention or usual care *Duration*: from the 4th week to the 12th month. *Recruitment*: from 2 postpartum weeks to 12 months	GWG	17 (14 RCTs included for meta-analysis) *Countries:* USA, Australia, Sweden Canada and UK. *Years*: 2006–2016	N/A

McGovern et al., 2024 JBI 10/11	To explore the perceptions of women on mHealth behavior change interventions for over-weight/obesity or GDM management during pregnancy and the postpartum period.	N = 604, (o = U) women with current diagnosis or history of GDM, overweight or obesity.	*Intervention:* 15 studies had mHealth interventions comprising online webinars, smartphone applications, tele-medicine, and health behavior change coaching *Control:* N/A *Duration:* N/A *Recruitment:* N/A	Psycho-behavioral outcomes	29 qualitative studies *Countries:* USA, UK, Australia, Canada, Ireland, Norway, Finland, Taiwan, Singapore *Years:* 2011–2024	mHealth as a support, mHealth as a personalized tool
Nightingale et al., 2023 JBI 9/11	To determine the effect of interventions incorporating motivational interviewing and/or cognitive therapy techniques on GWG outcomes.	n = 8030, (o = U) Pregnant women.	*Intervention:* interventions that include components of motivational interviewing (MI) and/or cognitive behaviour therapy (CBT) *Control:* Usual care *Duration:* N/A *Recruitment:* N/A	GWG	26 [U] *Countries:* USA, UK, Australia, Europe and Turkey. *Years*: 2002–2021	Motivational interviewing, cognitive therapy techniques
Shieh et al., 2018 JBI 9/11	To analyze healthy eating and PA strategies, particularly relevant to calorie intake and calories from macronutrients and effects of healthy eating and/or PA on gestational weight gain.	N = 7056, (o = 6473) Pregnant women with overweight or obesity.	*Intervention:* Exercise, diet or both. *Control:* Standard care *Duration:* from the 8th gestational week to the delivery *Recruitment*: by 28 gestational weeks.	GWG	23 (21 included in meta-analysis) *Countries:* Europe, Australia, New Zealand, Canada and Brazil. *Years:* 2009–2016	Goal setting
Sui et al., 2012 JBI 7/11	To systematically identify and evaluate the currently available literature relating to antenatal exercise interventions specifically targeting pregnant women who are overweight or obese.	N = 276, (o = 276) Women who were overweight or obese during pregnancy.	*Intervention:* Supervised antenatal exercise intervention *Control:* Routine standard antenatal care *Duration:* range between 10 and 16 weeks *Recruitment:* from 12 to 32 gestational weeks.	GWG	7 (6 RCTs, 1 QCT) *Countries:* Europe, Australia, North America, and South America. *Years:* 2004–2011	N/A

Wu et al., 2022 JBI 11/11	To assess the comparative efficacy of different interventions during pregnancy on preventing GDM and restricting GWG among women with overweight or obesity and establish the optimal strategy for clinicians.	N = 8877, (o = 8877) Overweight and obese pregnant women	*Intervention*: Diet, PA, combined, medication. *Control:* Standard care, placebo *Duration:* from 12 gestational weeks to six weeks postpartum *Recruitment:* from 9 to 20 gestational weeks	GDM, GWG	23 *Countries:* USA, UK, Ireland, Iran, China, Ireland, Netherlands, Austria, Poland, Spain, New Zealand, Australia, Italy, Finland, Denmark, Belgium and Norway. *Years:* 2008–2021	Behavioral changes, motivational text messages, self-weighing, online monitoring.
Yeo et al., 2016 JBI 9/11	To review randomized clinical trials targeting GWG in women with overweight or obesity by implementing prenatal lifestyle interventions.	N = 6869, (o = 5418) Pregnant women with overweight or obesity	*Intervention:* Lifestyle intervention (PA and or diet) *Control:* Undefined *Duration:* From 9 gestational week to delivery *Recruitment: < 27 gestational weeks*	GWG	32 *Countries:* Europe, Australia, North America and South America Canada, *Years*: 2005–2016.	Assessment and goal setting Weigh monitoring
Yu et al., 2024 JBI 11/11	To identify the most Effective intervention methods for managing GWG in overweight and obese pregnant women by conducting a systematic review and Bayesian meta-analysis using both direct and indirect evidence	N = 16615 pregnant women with overweight or obesity. N = 8756 in the experimental group and N = 7859 in the control group.	*Intervention:* education, PA, diet, behavior modification, combination. Implementation: Remote (eHealth and mhealth), in-person, combination. *Control:* standard care *Duration:* from <10 to 40 gwk	GWG	60 RCTs Countries: Not mentioned Years: 2002–2023	Behavior modification

BMI body mass index (calculated as weight in kilograms divided by height in meters squared), CBA: Controlled before and after studies, CBT: cognitive behaviour therapy, CCT: Controlled clinical trial, GDM: Gestational diabetes mellitus, GWG: gestational weight gain, ITS: Interrupted time series design, MI: motivational interview, N/A: not applicable or not reported, PA: physical activity, PPWL: postpartum weight loss, PPWR: postpartum weight retention, QCT: quasi-randomized trial, RCT: Randomized controlled trial, U: unknown.

Appendix 5. Matrix of COM-B model, TDF domains, intervention functions and BCT (v1)

BCTv1	Intervention functions	Text description	CAPABILITY				OPPORTUNITY				MOTIVATION			
			Physical		Psychological		Social		Physical		Reflective		Auto	
			S	K	MAD	BR	SI	EN	B CAP	B CON	S/P ID	O	G	EM
Information about health consequences	Education, persuasion	Explain the benefits of regular circadian rhythm and healthy life habits		√						√				
Salience of consequences	Persuasion	Provide information about consequences of overweight for mother and child		√						√				√
Social comparison	Persuasion	PHNs were told about benefits of intervention based on previous literature		√			√		√		√			
Instruction on how to perform the behaviour	Education	PHNs were informed on how to use intervention components on practice	√											
Behavioural practice/rehearsal	Training	PHNs used Oura rings, to gain understanding on how to utilize the data at antenatal visits	√	√	√	√		√						
Self-monitoring of behaviour	Enablement	Women with overweight are given Oura rings to monitor health parameters Women with overweight fill food diary to monitor nutritional intake			√	√		√						
Adding objects to the environment	Enablement	Oura rings and E-food diary are given to women with overweight			√			√						
Goal setting (behaviour)	Enablement	Women with overweight set behavioral goals during antenatal visits based on Ouras data				√				√			√	
Goal setting (outcome)	Enablement	Women with overweight set outcome goals during antenatal visits (e.g., weight gain goals)				√				√	√		√	

Instruction on how to perform a behaviour	Education, persuasion, enablement	PHNs compare health parameters to national recommendations and use motivational interviewing focusing on helping individuals to identify and resolve any ambivalence about changing behavior.	√	√	√			√			√			
Feedback on behaviour	Persuasion	PHNs give feedback to the women based on the data of Oura and food diary								√	√			
Prompts/cues	Environmental restructure	Phone app reminds users regularly			√			√						
Review behavioural goals	Enablement, persuasion	PHNs give feedback to the women based on the data of Oura and food diary comparing behavioral goals and to revise them.								√	√			
Verbal persuasion about capability	Persuasion	PHNs use motivational interviewing to encourage healthier lifestyle of women with overweight based on the data of Oura and food diary							√			√		

S: Skills, K: Knowledge, MAD: Memory, attention and decision process, BR: Behavioral regulation, SI: Social influences, EN: Environmental context and resources, B CAP: Beliefs about capability, B CON: Beliefs about consequences, S/P ID: Social/professional role and identity, O: Optimism, G: Goals, EM: Emotions

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