Full title: A coparenting-focused intervention and new mothers' postpartum obesity risk: Focusing on body mass index during the transition to parenthood

Short title: Coparenting and maternal anthropometry

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Disclosure

The authors have nothing to disclose.

Abstract

Background: While postpartum is a key life-stage contributing to increased obesity risk for women, existing weight management interventions don't consider the role of a women's partner in reducing stress and supporting lifestyle change.

Objectives: 1) To assess the effect of an intervention enhancing coparenting relationship quality on maternal body mass index (BMI) from preconception to 12-months postpartum and 2) if intervention status moderated the association of change in cortisol with change in BMI.

Subjects/Methods: A randomized controlled trial assessing enhancing coparenting relationships in couples during pregnancy and postpartum (n=57) compared to standard care (n=53) from 2003-6. Heterosexual couples (n=110) were recruited during pregnancy expecting their first child, ≥ 18 years old and living together. The intervention was Family Foundations, consisting of 8 classes for couples at transition to parenthood focused on enhancing coparenting (4 during and 4 following pregnancy).

Results: The main outcome measure was change in maternal BMI and change in cortisol. There was less increase in BMI for mothers in the intervention compared to the control group (-1.03 ± 0.42 kg/m², $p=0.015$). There was an interaction between intervention status and cortisol change predicting BMI change ($p=0.026$) such that cortisol change significantly predicted BMI change among mothers in the control group ($p=0.049$) but not the intervention group ($p=0.204$).

Conclusion: A coparenting intervention improved maternal postpartum BMI with this effect potentially related to interventions ameliorating the negative effect of stress, as measured by cortisol, on BMI. The role of enhanced coparenting in improving maternal anthropometry and reduced future obesity risk in women warrants urgent attention.

Introduction

Overweight and obesity are crucial public health problems affecting 67% of adults(1) and associated with an elevated risk of chronic diseases such as type 2 diabetes mellitus, cardiovascular disease, cancer, poor mental health, infertility and pregnancy complications. Reproductive-aged women have the highest risk of weight gain compared to other population groups(2) and the perinatal period is a specific high risk period. Up to 50% of women who give birth are overweight or obese at their first antenatal visit(3), women retain between 0.5-3 kg postpartum and about 25-47% of women retain ≥ 4.5 kg by 1 year postpartum.(4,5) Weight retention postpartum is associated with poorer maternal, fetal and child outcomes in subsequent pregnancies, as well as adverse maternal outcomes such as cardiovascular disease and long-term maternal obesity in later life.(4-7) Maternal obesity also has consequences for fetal development and offspring, increasing the risk of being born large-for-gestational age, being overweight or obese as children or adults and developing type 2 diabetes, premature cardiovascular disease, and premature mortality in adult life.(7,8) The perinatal period is therefore a critical window for weight management interventions to improve maternal health to prevent long-term chronic disease risks and prepare for healthy pregnancies, as well as for the health of the next generation.

International evidence-based guidelines for weight management following pregnancy(8) recommend that women follow population-based recommendations for diet, exercise and sedentary behaviour to gradually lose weight after pregnancy and achieve and maintain a healthy weight long-term. Meta-analysis of randomised controlled trials report postpartum lifestyle (diet, exercise and/or behavioural) interventions decrease postpartum weight by 2.24 kg (95% CI -3.03, -1.45) in 33 studies and n=4 960 women.(9) However, significant gaps exist regarding the

translation of these interventions from research trials into practice because the postpartum period is a time when women are faced with additional barriers to maintaining a healthy lifestyle.(10) Women are faced with competing demands on their personal time such as raising children and managing the household which are often prioritized over personal health¹¹ making it difficult to participate in intensive intervention programs that produce the best weight loss outcomes.(10-13) Given the obstacles faced by perinatal women, their ability to make and sustain behavioural lifestyle change depends in large part on the support and cooperation from their partner.(14) It is therefore important to consider how to involve a woman's partner in supporting healthy lifestyle and weight management during pregnancy and after birth. Existing research indicates that father support (and presumably other partners and coparenting figures) has a positive influence on healthy behaviours among their partners during(15) and following(16) pregnancy. However, postpartum lifestyle and weight management interventions to date have been designed and implemented focusing on women working in isolation without the support of their partners which may limit their efficacy and impact.

Although little research has examined the role of partner support in lifestyle behaviour change during the perinatal period, it is also possible that partner support may impact maternal lifestyle behaviors and weight status by improving maternal antenatal and postpartum depression, anxiety and stress(17,18) given the association between partner support and maternal mental health(19) and antenatal and postpartum mental health and postpartum weight retention.(20,21) In the last two decades, emerging research on partners' influence on maternal mental health has found that "coparenting support", conceptualized as the support or coordination that parental figures exhibit in childrearing activities, is a primary influence on maternal mental health. Coparenting relations

can be conceptualized as comprised of four overlapping domains: (1) agreement on childrearing principles and practices; (2) support vs. undermining of each other in the parenting role; (3) parental division of labor; and (4) joint family management, referring to family system theory's "executive subsystem"--the coparental unit that ideally operates cohesively to shape family culture, guide interaction and achieve goals(22,23).

We have previously reported that an intervention designed to improve coparenting practices also enhances parent-child relationship quality and children's health including sleep patterns and self-soothing and long-term (5-7 years) emotional, behavioural and school adjustment.(17,18,24) These improvements in child health are related to both durable improvements in parental stress, depression and anxiety and in parenting quality.(17,18) We hypothesize that enhanced coparenting support leading to healthy ways to cope with stress would also lead to improvements in maternal lifestyle and anthropometry. However, there is currently no research examining the effect of coparenting intervention on improving maternal lifestyle and weight management following birth. The aim of this study was to examine our existing research to assess the effect of coparenting interventions on maternal anthropometry postpartum. This research will support our future goals of adapting coparenting interventions to include an additional focus on support for maternal lifestyle behaviours.

Materials and methods

Participants and Procedures

The Family Foundations study was a randomized, two-arm controlled trial exploring how supporting a coparenting relationship in first-time parents influences child and parent

outcomes.(18) The study was conducted over 2003-6. The recruitment and methodology has been described in detail previously.(18) Participants included 169 heterosexual couples recruited through hospitals located in Altoona and Harrisburg in Pennsylvania, USA. At the time of enrollment, participants were first-time expectant parents, at least 18 years old and living together. Couples were recruited at an average gestational age of 22.9 ± 5.3 years (Table 1). In this study, a posthoc analysis was performed where the data from 110 mothers who participated in the survey and saliva sample collection at wave 1 (pregnancy) and wave 3 (12 months postpartum) were analyzed to examine the intervention effect on maternal body mass index (BMI) change between preconception and 12 months postpartum. The study was approved by the Penn State University Institutional Review Board and all participants provided signed informed consent. This trial was registered at www.clinicaltrials.gov (NCT01901536).

Intervention

Couples were randomly assigned to the intervention group ($n = 89$, $n=57$ for this subanalysis) or to the control group ($n = 80$, $n=53$ for this subanalysis). Expectant parents in the intervention group participated in four, in-person sessions including didactic material, exercises and behavioural rehearsal before childbirth and four sessions after childbirth designed to help expectant parents to discuss how they could cooperate and support each other effectively after childbirth.(18) The program included key themes such as emotional self-management, conflict management, problem solving, communication and mutual support strategies that foster positive joint parenting of an infant applied to issues such as dividing labour, facilitating emotional security and providing stimulation.(18) Each group consisted of 6-10 couples and sessions were led by a male-female team who received 3 days of training. Expectant parents in the control group received a mailed

brochure about how to select quality childcare services and children's developmental stages. Couples in both conditions participated concurrently in standard childbirth education classes. The intervention and delivery has been described in detail elsewhere.(18) The average number of prenatal and postpartum sessions attended were 3.3 and 2.3 respectively with 84.2% and 56.1% of couples attending at least three prenatal and postpartum sessions respectively.

Outcomes

Data were collected at home visits for wave 1 (pregnancy), wave 2 (6 months postpartum) and wave 3 (12 months postpartum, average 13.6±0.9 months). Collected outcomes have been described in detail previously(18) and included demographic factors of maternal age, marital status (coded as married or not married), ethnicity (white (non-Hispanic white)/non-white (African American, Asian, Hispanic or other)), household income (\$US) and maternal education (years). These included depressive symptoms measured with a subset of 7 items from the Center for Epidemiological Studies Depression Scale,(25) anxiety measured with the 20-item short form of the Taylor Manifest Anxiety Scale,(26) hours of sleep in the past two weeks (including nighttime and naps), physical activity (how many times per week were you physically active) and breastfeeding for longer than six months (coded as breastfeeding or not breastfeeding). Height and weight were self-reported with BMI calculated as (weight (kg)/height (cm)²) at all waves in addition to a self-reported preconception weight.

Salivary cortisol was measured as previously reported(27,28) at wave 1 (pregnancy) and wave 3 (12 months postpartum). For this study, we utilized the first (baseline) sample." Participants were asked not to eat for one hour before sample collection as recent meals are associated with cortisol

levels. Samples were collected in the afternoon or early evening (80% after 4 pm) to restrict variations of cortisol with the typical circadian rhythm. Collected saliva samples were kept on ice, frozen within 8 hours, stored at -20°C, and transported to Salimetrics laboratories (State College, PA, United States). After arriving at the laboratories, samples were stored at -70°C and processed within two weeks for saliva cortisol assay. On the day of cortisol assay, saliva samples were thawed and centrifuged at 3 000 rpm for 15 minutes to exclude mucins. Using an enzyme immunoassay for saliva cortisol, saliva samples were assayed without any modification to the manufacturers recommended protocol: 25µL of saliva was used in this test and the sensitivity of saliva was ranged from 0.007µg/dL to 3.0µg/dL. After that, given that maternal baseline cortisol levels vary depending on maternal gestation week and data collection time of the day, regression models were run with these two predictors and constructed residualised cortisol scores. Five outliers were truncated to threshold levels based on distributional box plots. Residualised scores were then multiplied by a factor of ten in order to generate comparable variation across variables. At 12 months postpartum, the same procedures were repeated, with the exception that maternal gestation did not factor into residualised wave 3 baseline cortisol.

Statistical analysis

The aim of the analyses was to examine the association between maternal BMI change between preconception and 12 months postpartum, maternal cortisol change between pregnancy and 12 months postpartum (calculated as study end values (wave 3 at 12 months postpartum) minus study commencement values (preconception or wave 1 at pregnancy for BMI and cortisol respectively) and intervention status. Given that maternal BMI in pregnancy is predicted by the week of gestation, residualised BMI scores were generated by regression model using gestation week as a

predictor and BMI in pregnancy as an outcome variable. This residualised BMI score was included in all our analyses to represent maternal BMI in pregnancy. Independent t-tests were used to determine if cortisol, weight and BMI at each time point and the change from preconception or pregnancy (for cortisol) to 12 months postpartum differed by intervention status. We performed univariate regressions by testing the association between each predictor on maternal BMI change. Variables significant at $p < 0.10$ in the univariate analysis or based on hypothesis testing were included as covariates in the multivariate regression analysis with the final model including mothers' BMI in pregnancy, sleeping hours in pregnancy, physical activity in pregnancy, marital status at baseline and breastfeeding at 6-month postpartum. To examine whether a psychosocial couple-based prevention program could make a significant change, we also tested an interaction between maternal cortisol change and intervention status in multivariate regression model. To examine whether a psychosocial couple-based prevention program could make a significant change, we also conducted simple slope analysis for the significant interaction between maternal cortisol change and intervention status in the multivariate regression model. In the sample of 110 mothers, 87% were complete cases. Twelve mothers (10.9%) were missing in breastfeeding at wave 2, two mothers (1.8%) were missing in BMI at wave 1 or at wave 3, and one mother (0.9%) was missing in physical activity at wave 1. Multiple imputation was used to handle missing data (the number of imputations performed = 10 imputations). All data analyses were conducted in STATA 14 (College Station, Texas).

Results

Participant characteristics

Demographic and health-related characteristics of the participating mothers are presented in Table 1. The average age of mothers was 28.6 ± 4.8 years old at baseline. Of 110 mothers, 84.5% were married, the average annual household income at baseline was \$US64105.5 $\pm$ 34445.9, average duration of mothers' education was 15.2 ± 1.8 years, the majority (93.6%) were non-Hispanic whites, average week of gestation at recruitment was 22.2 ± 5.6 weeks and 60% had a boy. As previously reported, there were no significant differences in age, income, education, marital status, gestation weeks and mental health between these two groups.

Maternal weight and BMI

Table 2 reports maternal anthropometry (weight and BMI) from preconception, pregnancy and 12 months postpartum. The proportion of women who had an overweight or obese BMI ($>25 \text{ kg/m}^2$) at preconception was 41.8% for the overall group (45.6% for intervention group and 37.7% for control group with no significant differences by group). There was no significant difference by intervention status in maternal weight or BMI at preconception, in pregnancy or at 12 months postpartum in unadjusted analyses with a trend for a lower difference in weight ($-2.2 \pm 1.2 \text{ kg}$) and BMI ($-0.8 \pm 0.4 \text{ kg/m}^2$) change for the intervention group compared to the control group from preconception to 12 months postpartum.

Univariate and multivariate models for the change in maternal BMI

Univariate and multivariate regression results are presented in Table 3. On univariate analysis, BMI residual was positively and marital status was inversely associated with the change in maternal BMI from preconception to 12 months postpartum. On multivariate analysis, BMI residual was positively associated with the change in maternal BMI from preconception to 12

months postpartum. Furthermore, mothers in the intervention group were likely to experience significantly less BMI change between preconception and 12-month postpartum compared to mothers in the control group ($B = -1.03$, $SE = 0.42$, $p = 0.015$).

On further assessment of an interaction between intervention group status and maternal cortisol change from pregnancy to 12-month postpartum, the direct effect of intervention group status on maternal BMI change remained significant ($B = -0.97$, $SE = 0.41$, $p = 0.020$) and the direct effect of maternal cortisol change on maternal BMI change became significant ($B = 0.70$, $SE = 0.35$, $p = 0.049$). The interaction between intervention status and maternal cortisol change was also significant to predict maternal BMI change ($B = -1.31$, $SE = 0.58$, $p = 0.026$). Table 4 demonstrates how the association between maternal cortisol change and BMI change differs by intervention status using simple slope analysis. The cortisol change significantly predicted BMI change among mothers in the control group ($dy/dx = 0.70$, $p = 0.049$), specifically mothers who experienced a greater change in cortisol were more likely to experience a greater change in BMI. However, among mothers in the intervention group, BMI change was not associated with maternal cortisol change ($dy/dx = -0.61$, $p = 0.204$). Figure 1 demonstrates two separate regressions of the outcome, maternal BMI change, on the predictor of maternal cortisol change at specific values of the intervention status as a moderator.

Discussion

We report here for the first time that a preventive intervention designed to improve coparenting practices at the transition to parenthood also improved maternal anthropometry postpartum, resulting in less increase in maternal BMI from preconception to 12 months postpartum. We also

found that randomization to the coparenting intervention eliminated the inverse association of change in maternal cortisol with change in maternal BMI observed in the control group. This finding suggests that intervention participants were better able to maintain a healthy lifestyle and consequently retain less weight in the face of elevated levels of stress.

For families who were randomized to Family Foundations, there was an improvement in postpartum BMI retention, specifically an 0.8 kg/m² difference in the change in maternal BMI from preconception to 12 months postpartum. To our knowledge this is the first time that an effect of improving coparenting relationships on maternal anthropometry has been reported. The existing literature reporting on the impact of coparenting-related interventions focuses predominantly on child and parental social, psychological and clinical health outcomes.(17,18,24) The literature assessing interventions to reduce postpartum weight retention focuses solely on individual mother's lifestyle interventions encompassing diet, physical activity and/or behavioural change.(9) In meta-analyses, such interventions achieved impacts on weight change of 2.24 kg(9) which is comparable to our finding of an intervention impact of 2.2 kg. We highlight here the novel strategy of achieving improvements in maternal anthropometry through promoting support from partner and establishing high quality coparenting relationships at the challenging life stage of the transition to parenthood even in the absence of specific diet, physical activity and behavioural advice.

It is possible that incorporating aspects of coparenting interventions into lifestyle interventions may augment the magnitude of weight or BMI change already achieved in lifestyle programs—either in an additive or possibly multiplicative manner. The latter may come about as greater coparenting support would likely facilitate increased support and coordination among parents

regarding healthy eating and activity routines. In fact, a prior study of daily fluctuations in family relationships in the postpartum period found that on days that mothers exercised more than they usually did, mothers and fathers reported more arguing and conflict; the same was not true for days on which fathers exercised more than usual.(29) Furthermore, the benefits of Family Foundations on child social and psychological health has been demonstrated to be sustained at least to 7 years post birth by teacher report.(24) Given that postpartum lifestyle interventions have only shown benefits on maternal anthropometry at 15 months as the longest follow up,(30) it is also possible that the benefits of coparenting interventions on maternal anthropometry may be sustained longer-term. This warrants further investigation.

Exploring the mechanisms of benefit for our findings of improved maternal anthropometry is of crucial importance. The beneficial effect of a coparenting intervention on maternal lifestyle could be related to the positive influence of fathers supporting their partners' healthy behaviours. While weight management is recognised as generally challenging, postpartum women face additional unique barriers to maintaining a healthy lifestyle.(10) These include loneliness, lack of motivation, lack of time due to parenting and domestic tasks, and prioritisation of own health below that of their families.(31) A systematic review of 28 qualitative and quantitative studies identified a lack of physical and emotional support from partners for cooking, exercise, housework or childcare as a key barrier to adopting and maintaining a healthy lifestyle.(31) In keeping with this, partner support was associated with improved maternal diet and physical activity in lifestyle interventions with pregnant women(15) or mothers with preschool-aged children.(16) This is also consistent with prior research that a couples-based approach to reducing cardiovascular disease risk was more effective in improving lifestyle factors than an approach focused solely on the patient.(32) It

is therefore crucial to involve a woman's partner in both parenting and in supporting healthy lifestyle following birth.

We report here that the intervention appeared to eliminate the link between changes in maternal cortisol and BMI across the transition found in the control group. Stress is defined as where perceived demands exceed the capacity of an individual to adapt to the demands. Parenting stress occurs when the demands associated with parenting exceed the personal and social resources available to meet the demands.(33) Stress can result in endocrine system responses including alterations in the metabolism of cortisol, a glucocorticoid and steroid hormone with production controlled by the hypothalamic pituitary adrenal axis.(34) Our results therefore indicate that a worsening of maternal anthropometry from preconception to postpartum was associated with a worsening in markers of maternal stress for mothers in the control group. This suggests that mothers experiencing increased stress following childbirth may have less improvement in postpartum BMI and thus higher risk of obesity and long-term comorbidities. (35) This is consistent with prior research in the general population reporting both higher stress and cortisol are associated with weight gain(36) through mechanisms including activation of the hypothalamic pituitary adrenal axis, sympathoadrenal activity and increased reward-related or emotional eating. (37-40) Similarly, an association between stress and both lower physical activity and higher weight retention has also been reported postpartum.(41,42) Higher serum morning cortisol in late pregnancy in women with obesity was also associated with greater weight retention at 3 months postpartum(43) and higher conversion of cortisone to cortisol was associated with a lesser decrease in 12 months postpartum BMI.(44) While we note that these associations are not consistently reported,(45,46) our research supports that cortisol, as a marker of stress, is related to worsened

maternal anthropometry postpartum with implications for increasing long-term maternal obesity risk.

While the transition into parenthood is recognised as a highly stressful period for both mothers and fathers,(47-49) maternal parenting stress or poorer mental health is predicted by the level of perceived emotional or financial parenting support from partners.(14,19) Our previous research reported that Family Foundations reduced levels of parental stress from 6 months through 3.5 years postpartum,(17) likely by increasing support and reducing conflict. Other research has demonstrated that social(50) or family support(51) weakens the association between psychological(50) or economic stress(51) and higher maternal cortisol in women during pregnancy(50) or postpartum.(51) Here we report a similar finding in that Family Foundations protected mothers from the putative negative effects of cortisol on maternal BMI. This is also consistent with prior research reporting greater partner support(14) and positive emotions during discussions with partners(52) were associated with improved dietary intake (higher fibre and lower trans-fat intake)(14) and higher levels of walking(14) or leisure time physical activity(53) at in women at 6-8 months postpartum as key behaviours associated with improved postpartum weight management. Furthermore, in the general population stress management interventions including mindfulness resulted in decreases in cortisol awakening responses and less increase in weight over 4 months.(53,54)

We note study limitations including self-reported anthropometry and retrospective pre-conception weight report which can contribute to response and recall bias; we recommend use of prospective and objective measures in future research. While we controlled for a wide range of factors

potentially associated with postpartum BMI including sleep,(55) breastfeeding(56) and physical activity,(57) we lack data on other factors such as dietary intake. Gestational weight gain is a key predictor of postpartum weight retention(58) and in prior research mediated the associated between third-trimester perceived stress and postpartum weight retention.(59) Further research is thus also warranted examining the interrelationship between coparenting relationships, stress, cortisol and weight management across both pregnancy and postpartum. Future research should also consider factors potentially associated with alterations in cortisol including gestational age, seasonality and gestational weight gain and use of multiple samples, diurnal responses or stress related activity.(60) Furthermore, in addition to the demonstrated benefits of Family Foundations on birth outcomes and child emotional and psychological health, which may be mediated by improvements in maternal psychological health,(17,18,24) there may also be potential benefits on other outcomes including childhood and paternal obesity(49) which should be explored.

Maternal postpartum weight retention is a significant public health problem and associated with adverse maternal, obstetric, fetal and child consequences including an increased risk of long-term maternal cardiovascular disease and obesity in later life. We found that a coparenting-focused intervention, Family Foundations, improved maternal postpartum anthropometry, with this effect potentially related to the intervention ameliorating the negative effect of stress, as measured by cortisol, on lifestyle, weight and BMI. The potential of improving coparenting relationship for improving maternal anthropometry therefore warrants urgent attention. Future research should investigate whether combining postpartum coparenting lifestyle interventions could augment and sustain anthropometric improvements and additional benefits on child and paternal anthropometry.

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References

1. Cameron AJ, Welborn TA, Zimmet PZ, Dunstan DW, Owen N, Salmon J, Dalton M, Jolley D, Shaw JE. Overweight and obesity in Australia: the 1999-2000 Australian Diabetes, Obesity and Lifestyle Study (AusDiab). *The Medical journal of Australia*. 2003;178(9):427-432.
2. Williamson DF, Kahn HS, Remington PL, Anda RF. The 10-year incidence of overweight and major weight gain in US adults. *Archives of internal medicine*. 1990;150(3):665-672.
3. AIWH. Australia's mothers and babies data visualisations. Canberra: Australian Institute of Health Welfare; 2020.
4. Ehrlich SF, Hedderson MM, Feng J, Davenport ER, Gunderson EP, Ferrara A. Change in body mass index between pregnancies and the risk of gestational diabetes in a second pregnancy. *Obstetrics and gynecology*. 2011;117(6):1323.
5. Luke S, Kirby RS, Wright L. Postpartum weight retention and subsequent pregnancy outcomes. *The Journal of perinatal & neonatal nursing*. 2016;30(4):292-301.
6. Wallace JM, Bhattacharya S, Campbell DM, Horgan GW. Inter-pregnancy weight change and the risk of recurrent pregnancy complications. *PloS one*. 2016;11(5):e0154812.
7. Farpour-Lambert NJ, Ells LJ, Martinez de Tejada B, Scott C. Obesity and weight gain in pregnancy and postpartum: an evidence review of lifestyle interventions to inform maternal and child health policies. *Frontiers in Endocrinology*. 2018;9:546.
8. NICE. Dietary interventions and physical activity interventions for weight management before, during and after pregnancy. London, UK.: National Institute for Health and Clinical Excellence. 2010.

9. Lim S, Liang X, Hill B, Teede H, Moran LJ, O'Reilly S. A systematic review and meta-analysis of intervention characteristics in postpartum weight management using the TIDieR framework: A summary of evidence to inform implementation. *Obesity Reviews*. 2019;20(7):1045-1056.
10. Buelo A, Kirk A, Lindsay R, Jepson R. Exploring the effectiveness of physical activity interventions in women with previous gestational diabetes: A systematic review of quantitative and qualitative studies. *Preventive medicine reports*. 2019:100877.
11. Kragelund Nielsen K, Groth Grunnet L, Terkildsen Maindal H, Workshop DDA, Speakers W. Prevention of Type 2 diabetes after gestational diabetes directed at the family context: a narrative review from the Danish Diabetes Academy symposium. *Diabetic Medicine*. 2018;35(6):714-720.
12. Parsons J, Ismail K, Amiel S, Forbes A. Perceptions among women with gestational diabetes. *Qualitative health research*. 2014;24(4):575-585.
13. Jones C, Burns S, Howat P, Jancey J, McManus A, Carter O. Playgroups as a setting for nutrition and physical activity interventions for mothers with young children: exploratory qualitative findings. *Health Promotion Journal of Australia*. 2010;21(2):92-98.
14. Faleschini S, Millar L, Rifas-Shiman SL, Skouteris H, Hivert MF, Oken E. Women's perceived social support: associations with postpartum weight retention, health behaviors and depressive symptoms. *BMC Womens Health*. 2019;19(1):143.
15. Shah MK, Kieffer EC, Choi H, Schumann C, Heisler M. Mediators and moderators of the effectiveness of a community health worker intervention that improved dietary outcomes in pregnant Latino women. *Health Education & Behavior*. 2015;42(5):593-603.

16. Miller YD, Trost SG, Brown WJ. Mediators of physical activity behavior change among women with young children. *American Journal of Preventive Medicine*. 2002;23(2):98-103.
17. Feinberg ME, Jones DE, Kan ML, Goslin MC. Effects of family foundations on parents and children: 3.5 years after baseline. *J Fam Psychol*. 2010;24(5):532-542.
18. Feinberg ME, Kan ML. Establishing family foundations: intervention effects on coparenting, parent/infant well-being, and parent-child relations. *J Fam Psychol*. 2008;22(2):253-263.
19. Harmon DK, Perry AR. Fathers' unaccounted contributions: Paternal involvement and maternal stress. *Families in Society*. 2011;92:176-182.
20. Hartley E, Hill B, McPhie S, Skouteris H. The associations between depressive and anxiety symptoms, body image, and weight in the first year postpartum: a rapid systematic review. *J Reprod Infant Psychol*. 2018;36(1):81-101.
21. Salehi-Pourmehr H, Niroomand S, Shakouri SK, Asgarlou Z, Farshbaf-Khalili A. Association Between Antenatal and Postpartum Depression and Anxiety with Weight Retention 1 Year After Childbirth: A Longitudinal Study. *Community Ment Health J*. 2018;54(8):1284-1294.
22. Kress AM, Hartzel MC, Peterson MR. Burden of disease associated with overweight and obesity among U.S. military retirees and their dependents, aged 38-64, 2003. *Preventive Medicine*. 2005;41(1):63-69.
23. Fryar CD, Carroll MD, Ogden CL. Prevalence of overweight and obesity among children and adolescents aged 2-19 years: United States, 1963-1995 through 2013-2014. In: Statistics NCfH, ed. Vol 2017: National Center for Health Statistics; 2016.

24. Feinberg ME, Jones DE, Roettger ME, Solmeyer A, Hostetler ML. Long-term follow-up of a randomized trial of Family Foundations: Effects on children's emotional, behavioral, and school adjustment. *Journal of Family Psychology*. 2014;28(6):821-831.
25. Radloff LS. The CES-D scale: a self-report depression scale for research in the general population. *Appl Psychol Meas*. 1977;1:385-401.
26. Taylor JA. A personality scale of manifest anxiety. *J Abnorm Psychol*. 1953;48(2):285-290.
27. Feinberg ME, Roettger ME, Jones DE, Paul IM, Kan ML. Effects of a psychosocial couple-based prevention program on adverse birth outcomes. *Maternal & Child Health Journal*. 2015;19(1):102-111.
28. Feinberg ME, Jones DE, Granger DA, Bontempo D. Relation of intimate partner violence to salivary cortisol among couples expecting a first child. *Aggress Behav*. 2011;37(6):492-502.
29. Feinberg ME, Jones DE, McDaniel BT, Liu S, Almeida D. New fathers' and mothers' daily stressors and resources influence parent adjustment and family relationships. *Monographs of the Society of Research in Child Development*. 2019;84(1):18-34.
30. Lioret S, Campbell KJ, Crawford D, Spence AC, Hesketh K, McNaughton SA. A parent focused child obesity prevention intervention improves some mother obesity risk behaviors: the Melbourne inFANT program. *The international journal of behavioral nutrition and physical activity*. 2012;9:100.
31. Makama M, Awoke MA, Skouteris H, Moran LJ, Lim S. Barriers and facilitators to a healthy lifestyle in postpartum women: A systematic review of qualitative and quantitative studies in postpartum women and healthcare providers. *Obes Rev*. 2021;22(4):e13167.

32. Philipps D. As economy roars, army falls thousands short of recruiting goals. *The New York Times* 2018, September 22:A16.
33. Deater-Deckard K, Scarr S. Parenting stress among dual earner mothers and fathers: Are there gender differences? . *Journal of Family Psychology*. 1996;10:45-59.
34. Keller J, Gomez R, Williams G, Lembke A, Lazzeroni L, Murphy GM, Jr., Schatzberg AF. HPA axis in major depression: cortisol, clinical symptomatology and genetic variation predict cognition. *Mol Psychiatry*. 2017;22(4):527-536.
35. Linné Y, Dye L, Barkeling B, Rössner S. Long-term weight development in women: A 15-year follow-up of the effects of pregnancy. *Obesity research*. 2004;12(7):1166-1178.
36. Chao AM, Jastreboff AM, White MA, Grilo CM, Sinha R. Stress, cortisol, and other appetite-related hormones: Prospective prediction of 6-month changes in food cravings and weight. *Obesity (Silver Spring)*. 2017;25(4):713-720.
37. Geiker NRW, Astrup A, Hjorth MF, Sjodin A, Pijls L, Markus CR. Does stress influence sleep patterns, food intake, weight gain, abdominal obesity and weight loss interventions and vice versa? *Obes Rev*. 2018;19(1):81-97.
38. Sims R, Gordon S, Garcia W, Clark E, Monye D, Callender C, Campbell A. Perceived stress and eating behaviors in a community-based sample of African Americans. *Eat Behav*. 2008;9(2):137-142.
39. Moss RH, Conner M, O'Connor DB. Exploring the effects of daily hassles and uplifts on eating behaviour in young adults: The role of daily cortisol levels. *Psychoneuroendocrinology*. 2021;129:105231.

40. Ans AH, Anjum I, Satija V, Inayat A, Asghar Z, Akram I, Shrestha B. Neurohormonal Regulation of Appetite and its Relationship with Stress: A Mini Literature Review. *Cureus*. 2018;10(7):e3032.
41. Whitaker K, Young-Hyman D, Vernon M, Wilcox S. Maternal stress predicts postpartum weight retention. *Matern Child Health J*. 2014;18(9):2209-2217.
42. Urizar GG, Hurtz SQ, Ahn DK, King AC, Albright CL, Atienza AA. Influence of maternal stress on successful participation in a physical activity intervention: the IMPACT Project. *Women Health*. 2005;42(4):63-82.
43. Mina TH, Denison FC, Forbes S, Stirrat LI, Norman JE, Reynolds RM. Associations of mood symptoms with ante- and postnatal weight change in obese pregnancy are not mediated by cortisol. *Psychol Med*. 2015;45(15):3133-3146.
44. Rogers SL, Hughes BA, Tomlinson JW, Blissett J. Cortisol metabolism, postnatal depression and weight changes in the first 12 months postpartum. *Clinical endocrinology*. 2016;85(6):881-890.
45. Collings R, Hill B, Skouteris H. The influence of psychological factors on postpartum weight retention 12 months post-birth. *J Reprod Infant Psychol*. 2018;36(2):177-191.
46. Straub H, Simon C, Plunkett BA, Endres L, Adam EK, McKinney C, Hobel CJ, Thorp JM, Raju T, Shalowitz M. Evidence for a Complex Relationship Among Weight Retention, Cortisol and Breastfeeding in Postpartum Women. *Matern Child Health J*. 2016;20(7):1375-1383.

47. Razurel C, Kaiser B, Sellenet C, Epiney M. Relation between perceived stress, social support, and coping strategies and maternal well-being: a review of the literature. *Women Health*. 2013;53(1):74-99.
48. Perren S, von Wyl A, Burgin D, Simoni H, von Klitzing K. Depressive symptoms and psychosocial stress across the transition to parenthood: associations with parental psychopathology and child difficulty. *J Psychosom Obstet Gynaecol*. 2005;26(3):173-183.
49. Saxbe D, Rossin-Slater M, Goldenberg D. The transition to parenthood as a critical window for adult health. *Am Psychol*. 2018;73(9):1190-1200.
50. Giesbrecht GF, Poole JC, Letourneau N, Campbell T, Kaplan BJ, Team APS. The buffering effect of social support on hypothalamic-pituitary-adrenal axis function during pregnancy. *Psychosom Med*. 2013;75(9):856-862.
51. Jewell SL, Luecken LJ, Gress-Smith J, Crnic KA, Gonzales NA. Economic Stress and Cortisol Among Postpartum Low-Income Mexican American Women: Buffering Influence of Family Support. *Behav Med*. 2015;41(3):138-144.
52. Hutt RL, Moore GA, Mammen MA, Symons Downs D. Postpartum Mothers' Leisure-Time Exercise Behavior is Linked to Positive Emotion During Partner Discussions. *Res Q Exerc Sport*. 2017;88(4):447-454.
53. Daubenmier J, Kristeller J, Hecht FM, Maninger N, Kuwata M, Jhaveri K, Lustig RH, Kemeny M, Karan L, Epel E. Mindfulness Intervention for Stress Eating to Reduce Cortisol and Abdominal Fat among Overweight and Obese Women: An Exploratory Randomized Controlled Study. *J Obes*. 2011;2011:651936.

54. Urizar GG, Jr., Yim IS, Rodriguez A, Schetter CD. The SMART Moms Program: A Randomized Trial of the Impact of Stress Management on Perceived Stress and Cortisol in Low-Income Pregnant Women. *Psychoneuroendocrinology*. 2019;104:174-184.
55. Siega-Riz AM, Herring AH, Carrier K, Evenson KR, Dole N, Deierlein A. Sociodemographic, perinatal, behavioral, and psychosocial predictors of weight retention at 3 and 12 months postpartum. *Obesity (Silver Spring)*. 2010;18(10):1996-2003.
56. Baker JL, Gamborg M, Heitmann BL, Lissner L, Sorensen TI, Rasmussen KM. Breastfeeding reduces postpartum weight retention. *The American journal of clinical nutrition*. 2008;88(6):1543-1551.
57. Ohlin A, Rossner S. Trends in eating patterns, physical activity and socio-demographic factors in relation to postpartum body weight development. *Br J Nutr*. 1994;1994(71):4.
58. Rong K, Yu K, Han X, Szeto IM, Qin X, Wang J, Ning Y, Wang P, Ma D. Pre-pregnancy BMI, gestational weight gain and postpartum weight retention: a meta-analysis of observational studies. *Public Health Nutr*. 2015;18(12):2172-2182.
59. Leonard KS, Adams EL, Savage JS, Paul IM, Kraschnewski JL, Pattison KL, Kjerulff KH, Symons Downs D. Influence of prenatal perceived stress on postpartum weight retention is mediated by high gestational weight gain in women with overweight. *Clin Obes*. 2021;11(3):e12446.
60. Aubuchon-Endsley NL, Bublitz MH, Stroud LR. Pre-pregnancy obesity and maternal circadian cortisol regulation: Moderation by gestational weight gain. *Biol Psychol*. 2014;102:38-43.

Figure Legends

586 Figure 1. Interaction plot between maternal cortisol change, maternal BMI change and intervention
587 status

588

589 **Tables**

590 Table 1: Demographic and health-related characteristics at baseline

591 Table 2: Changes in maternal cortisol, weight and BMI

592 Table 3: Univariate and multivariate regression models for the change in mother's BMI pre-
593 conception to 12 months postpartum (wave 3)

594 Table 4: Simple slope analysis for the interaction between maternal cortisol change and
595 intervention status predicting maternal BMI change

596

597 **Table 1. Demographic and health-related characteristics at baseline**

	All (n = 110)	Control (n = 53)	Intervention (n = 57)
Mother's age (years) (w1)	28.6 (4.8)	28.8 (5.4)	28.3 (4.2)
Marital status (w1)			
Married	93 (84.5%)	46 (86.8%)	47 (82.5%)
Non-married	17 (15.5%)	7 (13.2%)	10 (17.5%)
Mother's race/ethnicity (w1)			
White	103 (93.6%)	50 (94.3%)	53 (93.0%)
Non-white	7 (6.4%)	3 (5.6%)	4 (7.0%)
Gestation week (w1)	22.2 (5.6)	22.7 (5.6)	21.7 (5.6)
First trimester	3 (2.7%)	2 (3.8%)	1 (1.8%)
Second trimester	83 (75.5%)	38 (71.7%)	45 (79.0%)
Third trimester	24 (21.8%)	13 (24.5%)	11 (19.3%)
Child gender (w2)			
Girl	44 (40.0%)	19 (35.9%)	25 (43.9%)
Boy	66 (60.0%)	34 (64.2%)	32 (56.1%)
Household income (US\$, w1)	64105.5 (34445.9)	65518.9 (36100.0)	62767.9 (33075.9)
Mother's education (years; w1)	15.2 (1.8)	15.4 (1.9)	15.0 (1.7)
Mother's depression (w1)	0.5 (0.5)	0.4 (0.4)	0.5 (0.6)
Mother's anxiety (w1)	7.0 (3.8)	6.7 (3.9)	7.3 (3.6)
Mother's cortisol (w1)	-0.03 (0.4)	-0.03 (0.5)	-0.03 (0.4)

Mother's sleep (hours/night) (w1)	7.7 (1.3)	7.6 (1.3)	7.7 (1.4)
Mother's physical activity (times/week physically active) (w1)	1.6 (1.8)	1.6 (1.8)	1.6 (1.9)

598 BMI: Body mass index

599 Data are presented as mean (SD) or n (%)

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604 **Table 2. Changes in maternal cortisol, weight and BMI**

		Pre-conception	Pregnancy (w1)	12 months postpartum (w3)	Unadjusted difference - Preconception to 12 months postpartum*
Cortisol (µg/dL)	Intervention	-	-0.03 (0.04)	0.05 (0.06)	0.08 (0.08)
	Control	-	-0.03 (0.06)	-0.06 (0.10)	-0.03 (0.12)
	Difference	-	-0.01 (0.08)	0.10 (0.11)	0.11 (0.14)
		-	<i>p</i> = 0.913	<i>p</i> = 0.370	<i>p</i> = 0.436
Weight (kg)	Intervention	69.1 (2.0)	76.3 (2.2)	70.9 (2.3)	1.8 (0.9)
	Control	66.2 (2.2)	73.9 (2.2)	70.5 (2.5)	3.9 (0.8)
	Difference	2.9 (3.0)	2.5 (3.1)	0.3 (3.4)	-2.2 (1.2)
		<i>p</i> = 0.329	<i>p</i> = 0.431	<i>p</i> = 0.921	<i>p</i> = 0.075
BMI (kg/m ²)	Intervention	25.6 (0.7)	28.3 (0.8)	26.3 (0.9)	0.7 (0.3)
	Control	24.3 (0.7)	27.2 (0.7)	25.9 (0.8)	1.4 (0.3)
	Difference	1.3 (1.0)	1.1 (1.1)	0.4 (1.2)	-0.8 (0.4)
		<i>p</i> = 0.209	<i>p</i> = 0.301	<i>p</i> = 0.753	<i>p</i> = 0.082

605 Data were analysed by independent t-test and are presented as mean (standard error of the mean)

606 BMI: body mass index; M: mean; SE: standard error

607 * Unadjusted difference from wave 1 (pregnancy) to wave 3 (12 months postpartum)

608

609

Table 3. Univariate and multivariate regression models for the change in mother's BMI pre-conception to 12 months postpartum (wave 3)

	Crude B (95% CI)	β	p- value	Adjusted B (95% CI)	β	p- value
Cortisol change (w3–w1)	0.30 (-0.30, 0.90)	0.24	0.319	0.27 (-0.32, 0.85)	0.21	0.366
Intervention status						
Control	(Reference)			(Reference)		
Intervention	-0.77 (-1.65, 0.10)	-0.39	0.082	-1.03 (-1.86, -0.20)	-0.51	0.015
BMI residual (w1)	0.12 (0.04, 0.19)	0.64	0.002	0.11 (0.03, 0.19)	0.59	0.006
Marital status (w1)						
Non-married	(Reference)			(Reference)		
Married	-1.25 (-2.47, -0.03)	-0.52	0.046	-1.18 (-2.39, 0.03)	-0.50	0.056
Sleeping hours (w1)	-0.04 (-0.36, 0.29)	-0.06	0.819	-0.04 (-0.35, 0.26)	-0.07	0.778
Physical activity (w1)	-0.14 (-0.38, 0.10)	-0.23	0.248	-0.08 (-0.30, 0.15)	-0.12	0.508
Breastfeeding (w2)	-0.97 (-1.88, -0.07)	-0.54	0.035	-0.70 (-1.56, 0.17)	-0.39	0.111

BMI: Body mass index

Data were analysed by univariate (crude regression coefficients) and multivariate regression results (adjusted regression coefficients)

Table 4. Simple slope analysis for the interaction between maternal cortisol change and intervention status predicting maternal BMI change

	Categorical Moderator	
	Control group	Intervention group
Simple slope	0.70	-0.61
Standard error	0.35	0.48
T-value	2.00	-1.28
Significance	0.049	0.204
Degrees of freedom	94.03	

BMI: body mass index

Figure 1. Interaction plot between maternal cortisol change, maternal BMI change and intervention status

Data are presented as mean and SD and were analysed using simple slope analysis.

The light grey solid line indicates significant slope ($p=0.049$) between mother's cortisol change and BMI change for the control group while the dark grey dotted line indicates nonsignificant slope ($p=0.204$) for the intervention group.