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Changing diet and physical activity to reduce gestational weight gain: a meta-analysis

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Summary

Excessive pregnancy weight gain is associated with adverse maternal and child health outcomes. Intervention developers have assumed that adopting a healthier diet and increasing physical activity in pregnancy can limit weight gain, but evaluations of such interventions have yielded mixed results. Recent reviews of this literature have not identified defining characteristics of effective interventions. We systematically reviewed 10 published controlled trials of interventions that aimed to reduce gestational weight gain through changes in diet or physical activity. Characteristics of the sample, intervention content and delivery, and methodology were categorized. Meta-analysis showed that, overall, diet and physical activity change was effective in reducing gestational weight gain, but there was considerable heterogeneity in outcomes. Our analysis points to sample characteristics and aspects of intervention design, content, delivery and evaluation which differ between studies and may explain variation in effectiveness. Failure to evaluate changes in behaviour or its psychological determinants, and under-reporting of intervention content, may obscure identification of the processes by which weight change is effected. This limits our ability to discern active intervention ingredients. We suggest that behaviour-based gestational weight gain reduction interventions be more systematically designed, evaluated and reported to build on insights from behavioural science.

Keywords: Activity, behaviour change, nutrition, pregnancy.

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Introduction

Excessive gestational weight gain (GWG) has been associated with adverse maternal and child health outcomes. While the definition of 'excessive' gain differs according to pre-pregnancy body mass index (BMI) (1), mothers who gain more than their recommended weight experience higher incidence of gestational diabetes and pre-eclampsia, and the child faces increased risk of macrosomia and stillbirth (2,3). Excessive GWG has also been linked with an increased risk of offspring obesity, with higher levels of adiposity or BMI reported in infancy, childhood and adulthood (4–6). Recent studies have related higher GWG to greater post-partum weight retention (7,8), and longer-term effects on obesity risk (9,10).

Gestational weight gain within recommended limits is thought to improve pregnancy outcome and reduce childhood obesity. National guidelines for prenatal care in the USA and UK recommend that professionals prescribe a nutritionally balanced diet and regular physical activity (PA) to pregnant women to reduce excessive GWG (1,11). Yet, the results of studies that have evaluated the efficacy of diet and PA interventions for minimizing GWG have been mixed (2,3,12–14). A recent meta-analysis of nine intervention trials showed that promotion of healthy diet and PA in pregnancy is, overall, effective in minimizing GWG (14),

but considerable heterogeneity was observed. Diet and PA promotion has variously produced reductions in GWG (15), no change (16), or in one case negative effects, with intervention recipients gaining more weight than controls (17).

Behaviour-based GWG reduction intervention evaluations have been the subject of several recent reviews (2,3,12–14). However, given disparities in intervention effectiveness, conclusions have varied. One review concluded that diet and PA interventions in pregnancy have the potential to influence health outcomes (12), and one that further research is needed to understand how best to reduce GWG via dietary and PA change (2). Skouteris *et al*. (13) suggested that future behavioural interventions be augmented with efforts to target psychological factors such as mood, body image concerns, motivation and confidence to change behaviour. These conclusions are of limited utility for practitioners because they do not identify replicable components of previous effective GWG interventions. Two reviews attempted to summarize effective behaviour change methods: Olson (3) stated that 'healthy pregnancy weight gains can be achieved through monitoring weight gain, providing education and counselling, and physical activity sessions' (p. 420), and Streuling *et al*. (14) that 'educational interventions comprising physical activity and dietary counselling, usually combined with supplementary weight monitoring, may be successful in lowering GWG' (p. 686). These conclusions are problematic for two reasons. First, the focus on monitoring may be misplaced. Three interventions which used monitoring showed no effect (16,18,19). Conversely, an intervention based on dietary change only, which was not included in Streuling *et al*.'s meta-analysis (14) and did not appear to involve weight monitoring, was highly effective, with intervention recipients gaining 6.7 kg less than the control group (20). Second, no practical definition of 'counselling' was provided. It remains largely unclear what distinguishes effective 'counselling' (21,22) from ineffective 'counselling' (17–19).

Replication of effective interventions depends on clear description of the intervention components that covary with observed change. The only review to have systematically examined covariates of the GWG reduction effects of diet and PA behaviour change interventions found that interventions undertaken with women overweight prior to pregnancy, or evaluated using non-randomized trials were most effective (14). These insights indicate for whom intervention may be most beneficial and emphasize the need for methodological rigour in evaluation, but reveal little about how best to reduce GWG via diet and PA. Understanding the mechanisms of behaviour change requires identification of elements of intervention content that distinguish effective from ineffective interventions.

Previous reviews have described delivery and evaluation methods used in behaviour-based GWG reduction interventions (2,3,12–14), but have largely neglected possible variations in intervention content. While previous reviewers have noted the absence of psychological targets in the GWG behaviour change literature (13), theoretical and methodological tools from health psychology can nonetheless be used to categorize and evaluate intervention content (23). Specification of techniques associated with effective behaviour-based GWG interventions can generate hypotheses around best practice for behaviour change in pregnancy (24,25), and a taxonomy which provides standardized descriptions of discrete methods for modifying diet and PA (e.g. 'set behavioural goals', 'provide rewards contingent on successful behaviour', 'prompt review of behavioural goals') is available (26,27). Insights from the wider behaviour change literature suggest that interventions based on theory may be more effective (28), and coding the explicit theoretical basis of interventions for evidence synthesis helps to reveal whether and which theories better explain patterns of behaviour change (23,28). The technique taxonomy also links behaviour change techniques and theories, and so identification of effective techniques can be used to infer psychological pathways to behaviour change (29). Additionally, empirical and theoretical work predicts that interventions based on specific and achievable behavioural targets (e.g. 'consuming an additional portion of fruit per day') may be more successful in promoting change than those with more vague recommendations (e.g. 'eating a healthier diet'; 30).

The aim of this paper was to meta-analyse behaviour-based interventions that have targeted diet and/or PA changes to reduce GWG, and explore moderators of intervention effectiveness. Previous narrative, systematic and meta-analytic reviews of this literature are available (2,3,12–14), but these syntheses have not identified components of effective interventions. Our review is novel in that we deconstructed aspects of intervention content (i.e. theoretical basis, behaviour change techniques employed, behavioural targets specified) to identify characteristics of effective interventions and directions for future research. To ensure the review was comprehensive, we also coded for characteristics of delivery (e.g. delivery source), sample (e.g. gestational age) and outcome measures (e.g. time of follow-up).

Materials and methods

Selecting papers for review

Systematic search

Electronic databases (PsycInfo, Medline, Embase, AMED, HMIC, Cochrane Central Controlled Trials Register, Cochrane Health Technology Assessment) were searched in February 2010 for peer-reviewed English-language journal articles published between 1990 and 2010. Three search

filters were used for each database: one for interventions to prevent excessive GWG; one to specify controlled trial designs; and one to exclude samples with chronic health conditions.

One paper known to us but published too recently to be detected by the search was added to the dataset (31).

Reference lists of three previous reviews of the GWG intervention literature (2,3,12) were searched manually for additional references. (Two more recent reviews (13,14) were published after our search was completed.)

Inclusion criteria

Studies were included only if they reported an evaluation, based on quantitative data, of the efficacy of an intervention to improve diet and/or increase PA so as to prevent excessive weight gain in pregnant women aged 18+ years, where differences between an intervention and a control group on self-reported or objective behaviour or weight gain, measured prior to delivery, were reported. Interventions based on information provision only, or non-psychological interventions (i.e. medical or nutritional interventions) were excluded. We intended to exclude studies where participants had known pre-pregnancy mental or physical health problems, but none were found.

Search results and screening

In total, 169 unique records were identified, including one record obtained via a hand search of citations in previous reviews (22). Titles, abstracts and full texts were screened in sequential stages against inclusion criteria, with 10% of records independently assessed by a second coder. One hundred per cent agreement was observed at all three stages. Title screening removed 99 records, abstract screening removed a further 55 records, and four records were discarded after evaluation of full texts. Eleven papers were eligible for review. Two papers reported the same dataset, of which the less descriptive paper (32) was removed so that each intervention was coded once.

Ten independent papers, evaluating 11 unique interventions, were included in the review.

Contacting authors for additional information

All corresponding authors were contacted and asked to provide further written description of the intervention content. Seven authors responded, five of whom indicated that no additional information was available. Two authors (Isabelle Guelinckx, Tarja Kinnunen) sent further material which was used to code intervention content.

Data extraction

Sixty data segments were extracted from each paper. Data were extracted by a health psychologist (BG), and a registered dietitian (HC) independently coded 50% of data segments from each paper. Inter-coder agreement averaged at 98%. Disagreements were resolved via discussion.

Sample characteristics

Sample characteristics extracted related to sample size, age, socioeconomic status, pre-pregnancy BMI, whether BMI was used as a recruitment criterion, gestational age at study entry, parity and engagement in other health-relevant behaviours (e.g. smoking, vitamin use).

Treatment characteristics

Treatment characteristics were coded for both intervention and control treatments where possible. Extracted data related to which behaviour was targeted by the intervention (dietary behaviour or PA) and whether treatment was group- or individually based, tailored or generic to all participants.

Intervention content was coded for whether a behavioural recommendation was specified, whether the intervention was explicitly based on theory, and the behaviour change techniques employed. A reliable 19-item coding frame (33), which reveals the extent to which theory has been used in intervention design and evaluation, was used, but data could only be consistently extracted for one of these items (whether a theory or model of behaviour is mentioned). A 40-item taxonomy of behaviour change techniques (27) was used to code both intervention and control treatments. In line with taxonomy coding instructions (26,27), techniques were coded only where intervention description explicitly matched technique definitions. Coded aspects of treatment delivery included setting (e.g. clinic, hospital), delivery source (e.g. dietitian, personal trainers) and number of sessions. We also intended to code for adherence to the treatment protocol, but no such data were available in any of the trials.

Methodological characteristics

Methodological characteristics extracted related to trial design (i.e. randomized vs. non-randomized controlled trial) and study validity. We took Cochrane validity criteria as a starting point. Three criteria were used (allocation concealment, intention-to-treat analysis and losses to follow-up). Other criteria coded for elsewhere in our analysis (i.e. randomization, potential confounders and other sources of bias) and one criterion not uniformly relevant (blinding) were not included in validity assessment. Given the exploratory hypothesis-generating nature of our analyses, validity was operationalized using a scoring system. For allocation concealment, studies were allocated a score of 2 for concealment, 1 where not applicable (e.g. historical cohort designs) or where unclear, and 0 where allocation was applicable but not concealed. Studies reporting intention-to-treat analyses were awarded a score of 2, or 0 where no such analysis was conducted or it was unclear.

Following Streuling *et al.* (14), studies in which less than 10% of enrolled participants were lost to follow-up were awarded a score of 2, and a score of 0 where more than 10% were lost. Validity scores thus ranged from 0 to 6, with higher scores indicating greater validity.

Outcome data

The primary outcome of interest was weight gain (in kg) in pregnancy. Experimental and control group sample sizes, means and standard deviations were extracted. Diet and PA behaviour were extracted where reported. Where weight gain or behaviour measures were taken at multiple time points, we used data taken closest to birth.

Behaviour measures must reliably reveal whether a given behaviour has occurred. We therefore accepted e.g. the frequency with which given foods had been consumed, and metabolic equivalents (METs) as proxies for dietary behaviour and PA respectively (19). However, we rejected macronutrient intake (e.g. grams of energy, protein, fat, carbohydrate consumed (20)) as a behaviour index, because this does not reveal specific behavioural patterns.

Potential psychological determinants of behaviour (e.g. beliefs, attitudes, intentions) were not measured in any trials, so could not be included.

Meta-analytic strategy

Calculating effect sizes

Mean difference in weight gain (in kg) between intervention and control group was used as the effect size for analyses. Where necessary, weight outcomes were converted from pounds (lb) to kilograms (kg) prior to analysis, using the formula 1 lb = 0.45359237 kg. One three-arm trial assessed two experimental treatments relative to a single control group (34); this was entered into analysis as two trials of respective interventions. To avoid double-counting, the control group sample size was halved and rounded down to the nearest whole number (i.e. $43/2 = 21.5 \approx 21$). One study (17) reported intervention effects separately for normal weight groups (BMI 19.8–26.0) and overweight groups (BMI > 26.0). For review purposes, these were treated as two trials of one intervention.

Effect size analyses

Meta-analysis was undertaken using RevMan Version 5 (34) to generate weighted mean differences (WMD) with 95% confidence intervals. The purpose of this review was to identify sources of variation specific to previous studies, and so a fixed effects model was used, with inverse variances used to weight individual studies. Statistical heterogeneity was assessed using chi-square (χ^2) tests, for which significant values reflect heterogeneity around the mean study effect, and I^2, which describes the percentage of between-study variation attributable to heterogeneity rather than chance (35). I^2 values of over 50% indicate moderate and 75+ % high heterogeneity (35). Publication bias was assessed via visual inspection of funnel plots, whereby asymmetrical distribution of standard errors indicates bias.

Moderator analyses

Exploratory moderator analyses were performed to evaluate whether study characteristics covaried with intervention effectiveness. Meta-regression was deemed unsuitable due to the small number of trials available (36). Hence, subgroup analyses were undertaken. This involves dividing a dataset into subsets around a given study characteristic, to determine whether effect sizes vary significantly across subsets (37). A significant moderator is denoted where between-study heterogeneity (I^2) within each of the subgroups is lower than is observed for the overall study dataset (35). To maximize the number of trials available at each level of the potential moderator variable, moderators were dichotomized where possible.

Results

Twelve trials of 11 interventions reported in the 10 studies were included in the analysis (Table 1). One intervention (17) was evaluated separately for normal weight and overweight groups (these trials are numbered 17a and 17b, respectively, below). One study (31) evaluated two interventions: an 'active' and a 'passive' intervention (respectively labelled 31a and 31b).

Study characteristics

In total, 1656 participants (744 intervention, 912 control) were recruited to the 12 trials. Sample sizes ranged from 21 to 560 (mean 138 participants per trial).

Seven trials were conducted in North America (five USA, two Canada), and five in Europe (two in Belgium, and one in each of Denmark, Finland and Sweden). Seven trials used randomized control trial designs. Quasi-experimental control trials and historical cohort designs were each used in two trials. One trial used a time series design.

Eleven trials were of (ten) interventions targeting both diet and PA. One intervention focused on diet only (20). While weight gain was an outcome in all trials, behavioural outcomes (intake of specific foods or PA) were only assessed in six trials. (Five trials measured macronutrient intake (16–18,20), but these are not behaviour indices.) Both dietary and PA behavioural outcomes were reported in one trial (19). Two trials assessed but did not report effect sizes for diet and activity behaviour (17a,17b). Three trials, of interventions promoting both diet and PA, assessed activity but not dietary behaviour (16,31a,31b).

Table 1 Description of trials included in review

Reference, study design and country	Sample characteristics*	Treatment characteristics		Outcomes	
		Intervention treatment	Control treatment	Psychological and behaviour change	Weight gain
Asbee *et al.* (21) *Intervention target:* PA Diet/nutrition *Design:* Randomized control trial *Country:* USA	*n* = 100 *Weight* = all weights (underweight upwards) Intervention group *n* = 57 *Age* = 26.7 (±6.0) years *SES (education level)* = 68.4% high school graduate or below *Pre-pregnancy BMI* = 25.5 (±6.0) *Gestational age at recruitment* = 13.7 (±3.6) weeks *Parity* = 45.6% nulliparous *Other health behaviours* = 5.4% smokers (10 or less cigarettes per day) Control group *n* = 43 *Age* = 26.4 (±5.0) years *SES (education level)* = 65.1% high school graduate or below *Pre-pregnancy BMI* = 25.6 (±5.1) *Gestational age at recruitment* = 13.6 (±3.6) weeks *Parity* = 44.2% nulliparous *Other health behaviours* = 14% smokers (10 or less cigarettes per day)	*Brief description:* Counselling session re dietary and lifestyle choices in pregnancy, with specific behaviours and nutritional recommendations. Weight measured at routine obstetrical appointments; praise given for appropriate weight gain, diet and exercise goals reviewed if not Content *Recommended behaviour (diet)* = not stated *Recommended behaviour (PA)* = moderate PA 3–5 days a week *Theory-basedness* = no theory mentioned *Behaviour change techniques (re diet and PA)* = goal setting (behaviour); reviewing behavioural goals; rewards contingent on successful behaviour; feedback on performance *Group or individual treatment?* Individual *Tailored or generic treatment?* Individually tailored Delivery: *Setting* = clinic *Delivered by* = dietitian *Adherence to intervention protocol?* = not assessed *Number of sessions* = unclear (= number of obstetrical appointments)	*Brief description:* Group received booklet ('What to do when you're having a baby') and weight assessed at regular obstetrical appointments. Content *Recommended behaviour* = unclear *Behaviour change techniques* = none coded Delivery: *Setting* = clinic *Delivered by* = unclear/ self-administered	Psychological variables not measured Behaviour not measured	*Summary:* Positive effect *Time of follow-up (weight):* Day of delivery *Weight gain (intervention group):* 13.02 ± 5.67 kg *Weight gain (control group):* 16.15 ± 7.03 kg *Mean difference* = 3.13 kg *P for difference* = 0.01
Claesson *et al.* (15) *Intervention target:* PA Diet/nutrition *Design:* Non-randomized control trial *Country:* Sweden	*n* = 348 *Weight* = obese (BMI ≥ 30) Intervention group† *n*‡ = 143 *Age* = 29.7 (±4.48) years *SES (employment)* = 20% unskilled workers, 29% skilled workers, 5% lower white collar, 25% middle/high white collar or self-employed, 12% students, 9% unknown *Modal pre-pregnancy BMI* = 30–34.9 (64.5%) *Gestational age at recruitment* = 10–12 weeks *Parity* = 41.9% nulliparous *Other health behaviours* = 8.4% smokers Control group† *n*‡ = 161 *Age* = 30.2 (±4.92) years *SES (employment)* = 26% unskilled workers, 33% skilled workers, 6% lower white collar, 13% middle/high white collar or self-employed, 9% students, 14% unknown *Modal pre-pregnancy BMI* = 30–34.9 (65.8%) *Gestational age at recruitment* = 10–12 weeks *Parity* = 47.7% nulliparous *Other health behaviours* = 7.3% smokers	*Brief description:* Motivational interview and information provision session, supplemented with invitation to weekly supportive talk sessions and once- or twice-weekly aerobic classes Content *Recommended behaviour (PA & diet)* = not stated *Theory-basedness* = no theory stated *Behaviour change techniques (re diet and PA)* = Information on general consequences of behaviour; information on where and when to perform behaviour; instruction on how to perform behaviour; modelling/demonstration of behaviour; motivational interviewing *Group or individual treatment?* Individual and group *Tailored or generic treatment?* Individually tailored Delivery: *Setting* = clinic *Delivered by* = specially trained midwife *Adherence to intervention protocol?* = not assessed *Number of sessions* = various (one initial session, followed by optional weekly or twice-weekly sessions)	*Brief description:* Standard care (treatment as usual)	Psychological variables not measured Behaviour not measured	*Summary:* Positive effect *Time of follow-up (weight):* Day of delivery *Weight gain (intervention group):* 8.7 ± 5.51 kg *Weight gain (control group):* 11.3 ± 5.80 kg *Mean difference* = 2.6 kg *P for difference* < 0.001

Table 1 *Continued*

Reference, study design and country	Sample characteristics*	Treatment characteristics		Outcomes	
		Intervention treatment	Control treatment	Psychological and behaviour change	Weight gain
Gray-Donald *et al.* (18) *Intervention target:* PA Diet/nutrition *Design:* Time-series control trial *Country:* Canada	*n* = 219 *Weight* = all weights (underweight upwards) Intervention group *n* = 112 *Age* = 24.3 (±6.29) years *SES* = not reported *Pre-pregnancy BMI* = 30.8 (±6.85) *Gestational age at recruitment* = 17.1 (±7.06) weeks *Parity* = 31% nulliparous *Other health behaviours* = 52% smokers Control group *n* = 107 *Age* = 23.8 (±5.86) years *SES* = not reported *Pre-pregnancy BMI* = 29.6 (±6.45) *Gestational age at recruitment* = 18.5 (±6.92) weeks *Parity* = 37% nulliparous *Other health behaviours* = 42% smokers	*Brief description:* Community-based intervention for specific ethnic population (Aboriginal Cree). Dietary advice given, information on importance of healthy eating provided, 'supermarket tours and cooking demonstrations' and individual counselling sessions offered Content *Recommended behaviour (Diet)* = increased intake of dairy products and fruit and vegetables, decreased intake of high-energy foods with little nutritional value *Recommended behaviour (PA)* = not reported *Theory-basedness* = 'based on social learning theory' *Behaviour change techniques (re diet and PA)* = self-monitoring of behaviour; information on where and when to perform behaviour; modelling/demonstration of behaviour *Group or individual treatment?* Group and individual *Tailored or generic treatment?* Tailored and generic? Delivery: *Setting* = community *Delivered by* = nutritionists and health workers *Adherence to intervention protocol?* = not assessed *Number of sessions* = unclear	*Brief description:* Standard care (treatment as usual)	Psychological variables not measured Behaviour not measured	*Summary:* No effect *Time of follow-up (weight):* Day of delivery *Weight gain (intervention group):* 12.0 ± 6.4 kg *Weight gain (control group):* 13.2 ± 8.3 kg *Mean difference* = 1.2 kg *P for difference* = 0.29

Table 1 *Continued*

Reference, study design and country	Sample characteristics*	Treatment characteristics		Outcomes	
		Intervention treatment	Control treatment	Psychological and behaviour change	Weight gain
Guelinckx *et al.* (31): active intervention group vs control *Intervention target:* PA Diet/nutrition *Design:* Randomized control trial *Country:* Belgium	*n* = 85 *Weight* = obese (BMI ≥ 30) Intervention group *n* = 42 *Age* = 28.0 (±3.6) years *SES* = not reported *Pre-pregnancy BMI* = 34.1 (±4.5) *Gestational age at recruitment* = 9.3 (±2.8) weeks *Parity* = 47.6% nulliparous *Other health behaviours* = 7.1% smokers, 85.4% use vitamins Control group *n* = 43[4] *Age* = 29.4 (±4.4) years *SES* = not reported *Pre-pregnancy BMI* = 33.5 (±3.9) *Gestational age at recruitment* = 10.2 (±2.4) weeks *Parity* = 39.5% nulliparous *Other health behaviours* = 16.3% smokers, 81.4% use vitamins	*Brief description:* Participants given a brochure providing advice on nutrition and PA and tips to limited pregnancy-related weight gain. Also counselled by a nutritionist in 3 group sessions and 'techniques of behavioural modification', and methods of increasing PA discussed Content *Recommended behaviour (diet)* = replacing energy-dense foods with healthier alternatives, increasing wholewheat grain and low-fat dairy consumption, and reducing saturated fat consumption *Recommended behaviour (PA)* = not stated *Theory-basedness* = no theory mentioned *Behaviour change techniques (re diet and PA)* = none coded *Group or individual treatment?* Group and individual *Tailored or generic treatment?* Individually tailored Delivery: *Setting* = clinic *Delivered by* = nutritionist *Adherence to intervention protocol?* = not assessed *Number of sessions* = 3	*Brief description:* Standard care (treatment as usual)	Psychological variables not measured Behaviour: *Time of follow-up:* third trimester (exact time unknown) *Dietary behaviour:* not measured *PA behaviour:* *Indicator:* PA score (range 3–15, higher scores indicate more PA) Summary: no effect *Behaviour change from baseline (intervention group):* Decrease (baseline 7.47 ± 1.14; follow-up 7.14 ± 1.31) *Behaviour change from baseline (control group):* Decrease (baseline 7.42 ± 1.08; follow-up 6.80 ± 1.17).	*Summary:* No effect *Time of follow-up (weight):* ~39 weeks *Weight gain (intervention group):* 9.8 ± 7.6 kg *Weight gain (control group):* 10.6 ± 6.9 kg *Mean difference* = 0.8 kg *P for difference* = not reported (>0.05)
Guelinckx *et al.* (31): passive intervention group vs control *Intervention target:* PA Diet/nutrition *Design:* Randomized control trial *Country:* Belgium	*n* = 80 *Weight* = obese (BMI ≥ 30) Intervention group *n* = 37 *Age* = 28.7 (±4.0) years *SES* = not reported *Pre-pregnancy BMI* = 33.4 (±3.07) *Gestational age at recruitment* = 10.2 (±2.6) weeks *Parity* = 40.5% nulliparous *Other health behaviours* = 5.4% smokers, 76.5% use vitamins Control group *n* = 43[§] *Age* = 29.4 (±4.4) years *SES* = not reported *Pre-pregnancy BMI* = 33.5 (±3.9) *Gestational age at recruitment* = 10.2 (±2.4) weeks *Parity* = 39.5% nulliparous *Other health behaviours* = 16.3% smokers, 81.4% use vitamins	*Brief description:* participants given a brochure providing advice on nutrition and PA and tips to limited pregnancy-related weight gain Content *Recommended behaviour (diet)* = not stated *Recommended behaviour (PA)* = not stated *Theory-basedness* = no theory mentioned *Behaviour change techniques (re diet and PA)* = None coded *Group or individual treatment?* Individual *Tailored or generic treatment?* Generic Delivery: *Setting* = clinic *Delivered by* = unclear	*Brief description:* Standard care (treatment as usual)	Psychological variables not measured Behaviour: *Time of follow-up:* third trimester (exact time unknown) *Dietary behaviour:* Not measured *PA behaviour:* *Indicator:* PA score (range 3–15, higher scores indicate more PA) Summary: no effect *Behaviour change from baseline (intervention group):* Decrease (baseline 7.47 ± 1.14; follow-up 7.14 ± 1.31) *Behaviour change from baseline (control group):* Decrease (baseline 7.42 ± 1.08; follow-up 6.80 ± 1.17).	*Summary:* No effect *Time of follow-up (weight):* ~39 weeks *Weight gain (intervention group):* 10.9 ± 5.6 kg *Weight gain (control group):* 10.6 ± 6.9 kg *Mean difference* = –0.3 kg *P for difference* = not reported (>0.05)

Table 1 *Continued*

Reference, study design and country	Sample characteristics*	Treatment characteristics		Outcomes	
		Intervention treatment	Control treatment	Psychological and behaviour change	Weight gain
Hui *et al.* (16) *Intervention target:* PA Diet/nutrition *Design:* Randomized control trial *Country:* Canada	*n* = 45 *Weight* = all weights (underweight upwards) Intervention group *n* = 24 *Age* = 26.2 (±5.4) years *SES (family income)* = mean $41383 *Pre-pregnancy BMI* = 23.4 (±3.9) *Gestational age at recruitment* <26 weeks *Parity* = not reported *Other health behaviours* = not reported Control group *n* = 21 *Age* = 26.2 (±5.7) years *SES (family income)* = mean $40620 *Pre-pregnancy BMI* = 25.7 (±6.3) *Gestational age at recruitment* <26 weeks *Parity* = not reported *Other health behaviours* = not reported	*Brief description:* *PA:* participants instructed in group- and home-based exercises, taught how to self-monitor heart rate, steps etc, and given diaries for self-monitoring *Diet:* participants given personalized feedback on their self-reported food intake, and information if requested Content *Recommended behaviour (PA)* = exercise 3 to 5 times per week for 30–45 min per session *Recommended behaviour (diet)* = not stated *Theory-basedness* = no theory mentioned *Behaviour change techniques (PA)* = goal setting (outcome); modelling/demonstration of behaviour; self-monitoring of behaviour; instruction on how to perform the behaviour *Behaviour change techniques (diet)* Action planning; self-monitoring of behaviour; feedback on performance *Group or individual treatment?* Group (PA) Individual (diet) *Tailored or generic treatment?* Generic (PA) Individually tailored (diet) Delivery: *Setting* = community *Delivered by* = Professional trainers (PA) Student assistants (PA) Dietitian (diet) *Adherence to intervention protocol?* = not assessed *Number of sessions* = unclear (PA = weekly sessions)	*Brief description:* Participants given information containing dietary recommendations for healthy pregnancy. PA recommended. Content *Recommended behaviour* = not stated *Behaviour change techniques* = none coded Delivery: *Setting* = community *Delivered by* = unclear/ self-administered	Psychological variables not measured Behaviour: *Time of follow-up:* 32–36 weeks' gestation *PA behaviour:* *Indicator:* PA score (range 0–2, higher score indicates more vigorous PA) Summary: positive effect *Behaviour change from baseline (intervention group):* Increase (baseline 1.17 ± 0.87; follow-up 1.96 ± 0.20) *Behaviour change from baseline (control group):* Decrease (baseline 1.52 ± 0.68; follow-up 1.48 ± 0.68) *Dietary behaviour:* Not reported.	*Summary:* No effect *Time of follow-up (weight):* Unclear *Weight gain (intervention group):* 14.2 ± 5.3 kg *Weight gain (control group):* 14.2 ± 6.3 kg *Mean difference* = 0 kg *P for difference* = 1.00

Table 1 *Continued*

Reference, study design and country	Sample characteristics*	Treatment characteristics		Outcomes	
		Intervention treatment	Control treatment	Psychological and behaviour change	Weight gain
Kinnunen *et al.* (19) *Intervention target:* PA Diet/nutrition *Design:* Non-randomized control trial *Country:* Canada	*n* = 105 *Weight* = all weights (underweight upwards) Intervention group *n* = 49 *Age* = 27.6 (±4.5) years *SES (modal education)* = 57% basic or secondary education *Pre-pregnancy BMI* = 23.7 (±3.9) *Gestational age at recruitment* = 8–9 weeks *Parity* = 100% nulliparous *Other health behaviours* = 32% smokers Control group *n* = 56 *Age* = 28.8 (±4.1) years *SES (modal education)* = 43% university *Pre-pregnancy BMI* = 22.3 (±2.1) *Gestational age at recruitment* = 8–9 weeks *Parity* = 100% nulliparous *Other health behaviours* = 16% smokers	*Brief description:* *PA:* one primary counselling session and four boosters. Discussion of current PA levels, advice on how to increase PA, personalized PA plan. Optional weekly group exercise sessions *Diet:* one primary counselling session and three boosters. Comparison of current diet with recommendations, advice on how to enhance diet, and self-monitoring diary Content *Recommended behaviour (PA)* = unclear *Recommended behaviour (diet)* = consumption of (i) regular meals daily (including breakfast and at least one hot meal); (ii) five portions of fruit, vegetables and berries per day; (iii) high-fibre bread. Also, (iv) reduce intake of high-sugar snacks to less than one portion per day *Theory-basedness* = Theories cited: Precede–Proceed Transtheoretical model Behaviourally grounded model *Behaviour change techniques (PA):* Provide information on general consequences of behaviour; goal setting (behaviour); goal setting (outcome); barrier identification; review of behavioural goals; review of outcome goals; feedback on performance; information on where and when to perform behaviour; provide instruction; model/demonstrate behaviour; follow-up prompts *Behaviour change techniques (diet)* Goal setting (behaviour); barrier identification; review of behavioural goals; self-monitoring of behaviour; feedback on performance; provide instruction; follow-up prompts *Group or individual treatment?* Group and individual (PA) Individual (diet) *Tailored or generic treatment?* Generic and individually tailored (PA) Generic and individually tailored (diet) Delivery: *Setting* = clinic *Delivered by* = public health nurses *Adherence to intervention protocol?* = not assessed *Number of sessions* = PA: 5 (+additional optional weekly sessions) Diet: 4	*Brief description:* Standard care (treatment as usual)	Psychological variables not measured Behaviour: *Time of follow-up:* 36–37 weeks' gestation *PA behaviour:* *Indicator:* MET minutes per week Summary: no effect; exact scores and *P* values not reported *Behaviour change from baseline (intervention group):* Decrease (~1700 at 16–18 weeks; ~1400 at follow-up) *Behaviour change from baseline (control group):* Decrease (~1600 at 16–18 weeks; ~1500 at follow-up) *Dietary behaviour:* *Indicator(s):* Fruit, vegetables and berries, daily portions High-fibre bread as % of total bread consumed High-sugar snacks, daily portions Summary: Positive effect: significantly higher increase in fruit, vegetable and berry consumption, and high-fibre bread consumption, in intervention group *Behaviour change from baseline (intervention group):* Fruit, vegetable and berry consumption: increase (1.3 portions; baseline 2.5 ± 1.3; follow-up 3.8 ± 1.7) High-fibre bread consumption: decrease (baseline: 69% ± 27 of total bread; follow-up: 67% ± 29 of total bread) High-sugar snacks: no change (baseline 1.6 ± 1.5 daily portions; follow-up 1.6 ± 1.3 daily portions) *Behaviour change from baseline (control group):* Fruit, vegetable and berry consumption: increase (0.3 portions; baseline 2.9 ± 1.5; follow-up 3.2 ± 1.5) High-fibre bread consumption: decrease (baseline: 58% ± 25 of total bread; follow-up: 53% ± 24 of total bread) High-sugar snacks: increase (baseline 1.4 ± 0.9 daily portions; follow-up 1.8 ± 1.1 daily portions).	*Summary:* No effect *Time of follow-up (weight):* 36–37 weeks *Weight gain (intervention group):* 14.6 ± 5.4 kg *Weight gain (control group):* 14.3 ± 4.1 kg *Mean difference* = –0.3 kg *P for difference* = 0.77

Table 1 *Continued*

Reference, study design and country	Sample characteristics*	Treatment characteristics		Outcomes	
		Intervention treatment	Control treatment	Psychological and behaviour change	Weight gain
Olson *et al.* (39) *Intervention target:* PA Diet/nutrition *Design:* Historical cohort *Country:* USA	*n* = 560 *Weight* = normal to overweight (BMI ≥ 19.8 ≤ 29.0) Intervention group *n* = 179 *Modal age* = 20–40 years (93.9%) *SES (modal income)* = 62.6% high (>185% poverty line) Modal *pre-pregnancy BMI* = ≤26.0 (76.1%) *Gestational age at recruitment* <27 weeks *Parity* = 41.3% nulliparous *Other health behaviours* = 15.3% smokers Control group *n* = 381 *Modal age* = 20–40 years (93.7%) *SES (modal income)* = 56.7% high (>185% poverty line) Modal *pre-pregnancy BMI* = ≤26.0 (73.2%) *Gestational age at recruitment* <37 weeks *Parity* = 41.1% nulliparous *Other health behaviours* = 18% smokers	*Brief description (PA and diet):* Participants given leaflet containing tips for healthy eating and exercise in pregnancy. Also 5 motivational newsletters sent by mail Content *Recommended behaviour (PA)* = not stated *Recommended behaviour (diet)* = not stated *Theory-basedness* = no theory mentioned *Behaviour change techniques (PA and diet):* Goal setting (behaviour); self-monitoring of behaviour; self-monitoring of outcome; follow-up prompts *Group or individual treatment?* Unclear *Tailored or generic treatment?* Generic and individually tailored Delivery: *Setting* = hospital *Delivered by* = healthcare providers *Adherence to intervention protocol?* = not assessed *Number of sessions* = 1	*Brief description:* Standard care (treatment as usual)	Psychological variables not measured Behaviour not measured	*Summary:* No effect *Time of follow-up (weight):* Day of delivery *Weight gain (intervention group):* 14.10 ± 4.51 kg *Weight gain (control group):* 14.80 ± 4.68 kg *Mean difference* = 0.7 kg *P for difference* = 0.09
Polley *et al.* (17): normal weight groups *Intervention target:* PA Diet/nutrition *Design:* Randomized control trial *Country:* USA	*n* = 61 *Weight* = normal weight (BMI 19.8–26.0) *Age*¶ = 25.5 (±4.8) years *SES (modal education)* = 45% high school education or less *Pre-pregnancy BMI* = not reported *Gestational age at recruitment* = 14.5 (±3.5) weeks *Parity* = 47% nulliparous *Other health behaviours* = not reported Intervention group *n* = 30 Control group *n* = 31	*Brief description:* Information given on appropriate pregnant weight gain and importance of exercise and diet in pregnancy. Newsletters were sent to participants biweekly, with feedback given and subsequent targets agreed based on personal weight gain patterns Content *Recommended behaviour (diet)* = reduced high-fat food consumption and substituting healthier alternatives *Recommended behaviour (PA)* = increased walking, and 'developing more active lifestyle' *Theory-basedness* = no theory mentioned *Behaviour change techniques (re diet and PA)* = goal setting (behaviour); barrier identification/problem solving; review of behavioural goals; self-monitoring of behaviour; feedback on performance *Group or individual treatment?* Individual *Tailored or generic treatment?* Individually tailored Delivery: *Setting* = clinic *Delivered by* = postgraduate staff with nutritional or clinical training *Adherence to intervention protocol?* = not assessed *Number of sessions* = unclear	*Brief description:* Standard care (treatment as usual)	Psychological variables not measured Behaviour: neither group-specific behaviour scores nor effect sizes are reported.	*Summary:* No effect *Time of follow-up (weight):* 30 weeks *Weight gain (intervention group):* 15.4 ± 7.1 kg *Weight gain (control group):* 16.4 ± 4.8 kg *Mean difference* = 1.0 kg *P for difference* = not reported

Table 1 *Continued*

Reference, study design and country	Sample characteristics*	Treatment characteristics		Outcomes	
		Intervention treatment	Control treatment	Psychological and behaviour change	Weight gain
Polley *et al.* (17): overweight groups *Intervention target:* PA Diet/nutrition *Design:* Randomized control trial *Country:* USA	*n* = 59 *Weight* = overweight (BMI > 26.0) *Sample characteristics as above* Intervention group *n* = 27 Control group *n* = 22	*As above*	*As above*	*As above*	*Summary:* No effect: but intervention participants tended to gain *more* weight than did controls. *Time of follow-up (weight):* 30 weeks *Weight gain (intervention group):* 13.6 ± 7.2 kg *Weight gain (control group):* 10.1 ± 6.2 kg *Mean difference* = –3.5 kg *P for difference* = 0.09
Shirazian *et al.* (22) *Intervention target:* PA Diet/nutrition *Design:* Historical cohort *Country:* USA	*n* = 41 *Weight* = obese (BMI > 30) Intervention group *n* = 21 *Age* = 29.00 (±5.09) years *SES* = not reported *Pre-pregnancy BMI* = 36.20 (±5.23) *Gestational age at recruitment* ≤ 12 weeks *Parity* = 19% nulliparous *Other health behaviours* = not reported Control group *n* = 20 *Age* = 24.35 (±5.61) years *SES* = not reported *Pre-pregnancy BMI* = 34.24 (±5.33) *Gestational age at recruitment* ≤ 12 weeks *Parity* = 50% nulliparous *Other health behaviours* = not reported	*Brief description:* A multicomponent intervention aimed at promoting healthy eating and encouraging walking, with an overarching goal of gaining no more than 6.80 kg (15 lb). Participants received written materials, a food diary and pedometer, and attended six seminars to discuss issues around health in pregnancy, and at least five one-to-one counselling sessions Content *Recommended behaviour* = healthy eating, calorie counting, walking as exercise *Theory-basedness* = no theory mentioned *Behaviour change techniques:* Information on consequences of behaviour in general; goal setting (outcome); barrier identification/problem solving; self-monitoring of behaviour *Group or individual treatment?* Individual *Tailored or generic treatment?* Tailored Delivery: *Setting* = unclear *Delivered by* = unclear *Adherence to intervention protocol?* = not assessed *Number of sessions* = 11	*Brief description:* Standard care (treatment as usual)	Psychological variables not measured Behaviour not measured	*Summary:* Positive effect *Time of follow-up (weight):* Unclear *Weight gain (intervention group):* 8.06 ± 7.40 kg *Weight gain (control group):* 15.42 ± 7.52 kg *Mean difference* = 7.36 kg *P for difference* = 0.003

Table 1 *Continued*

Reference, study design and country	Sample characteristics*	Treatment characteristics		Outcomes	
		Intervention treatment	Control treatment	Psychological and behaviour change	Weight gain
Wolff *et al.* (20) *Intervention target:* Diet/nutrition *Design:* Randomized control trial *Country:* Denmark	$n = 50$ *Weight* = obese (BMI ≥ 30) Intervention group $n = 23$ *Age* = 28 (±4) years *SES* = not reported *Pre-pregnancy BMI* = 34.9 (±4) *Gestational age at recruitment* = 15 (±2) weeks *Parity* = not reported *Other health behaviours* = 100% non-smokers, 0.2% energy from alcohol Intervention group $n = 27$ *Age* = 30 (±5) years *SES* = not reported *Pre-pregnancy BMI* = 34.6 (±3) *Gestational age at recruitment* = 16 (±3) weeks *Parity* = not reported *Other health behaviours* = 100% non-smokers, 0.4% energy from alcohol	*Brief description:* Participants instructed by a dietician to eat a healthy diet based on official Danish dietary recommendations. Feedback given on eating patterns and improvements suggested where appropriate Content *Recommended behaviour* = none stated *Theory-basedness* = no theory mentioned *Behaviour change techniques:* Goal setting (outcome); Self-monitoring of behaviour; feedback on performance *Group or individual treatment?* Individual *Tailored or generic treatment?* Tailored Delivery: *Setting* = clinic *Delivered by* = dietitian *Adherence to intervention protocol?* = not assessed *Number of sessions* = 10	*Brief description:* Standard care (treatment as usual)	Psychological variables not measured Behaviour: not reported	*Summary:* Positive effect: Less weight gain in the intervention group than control group. *Time of follow-up (weight):* 36 weeks *Weight gain (intervention group):* 6.6 ± 7.2 kg *Weight gain (control group):* 13.3 ± 7.5 kg *Mean difference* = 6.7 kg *P for difference* = 0.002

*Age, pre-pregnancy BMI and gestational age are expressed as means unless otherwise stated.
†Due to lack of data specific to study completers, mean age, BMI and gestational age scores here include 44 participants who did not complete the study (15).
‡*n* here refers to the number of participants for whom weight gain data were available.
§This control group was used for two comparisons, and so sample size was halved ($n = 21$) for the purpose of analysis, to avoid double-counting.
¶Sample characteristics reported by Polley *et al.* (17) relate to the total sample (normal and overweight, intervention and control groups).
BMI, body mass index; PA, physical activity; SES, socioeconomic status.

Table 2 Validity of included trials

Reference	Allocation concealment?	Intention-to-treat analysis	Losses to follow-up (%)	Overall validity score (max score = 6)
Asbee *et al.* (21)	Yes	No	8	4
Claesson *et al.* (15)	N/A	No	5	3
Gray-Donald *et al.* (18)	N/A	Yes	32	3
Guelinckx *et al.*, active intervention (31)	Unclear	No	39	0
Guelinckx *et al.*, passive intervention (31)	Unclear	No	38	0
Hui *et al.* (16)	Unclear	No	13	0
Kinnunen *et al.* (19)	N/A	No	20	1
Olson *et al.* (39)	N/A	Unclear	0	2
Polley *et al.*, normal weight groups (17)	Unclear	Yes	6	4
Polley *et al.*, overweight groups (17)	Unclear	Yes	13	2
Shirazian *et al.* (22)	N/A	No	7	3
Wolff *et al.* (20)	Unclear	No	32	0

Given the paucity of studies that measured behaviour, meta-analysis was not performed on behavioural outcomes.

Physical activity was variously measured as exercise class attendance frequency (16), MET minutes per week (19) or general exercise questionnaires (17,31).

Dietary behaviour, evaluated in only one trial, was measured as consumption of fruit, berries and vegetables, high-fibre bread and high-sugar snacks (19).

Six trials were of interventions administered exclusively by dietitians, and one was of an intervention delivered by both dietitians and professional PA trainers (16). Two trials evaluated interventions delivered by healthcare workers, and one by a midwife. In two trials, it was unclear who delivered the intervention (22,31b).

Only two trials were of interventions explicitly reported to be theory-based: one was informed by Social Learning Theory (18), and one was based on multiple theories (the Precede–Proceed Model, the Transtheoretical Model and the Behaviourally Grounded Model (19)). However, theory was not mentioned in the Method section of either report and so it was unclear how it was used in the design of the intervention.

Validity scores varied from 0 (four trials) to 4 (two trials) (Table 2). Allocation was concealed in one of seven randomized trials, with concealment unclear in the remaining six of these trials. Three of the 12 trials were evaluated using an intention-to-treat analysis. For one trial it was unclear whether intention-to-treat analysis was performed. Percentage of participants lost to follow-up ranged from 0 to 39%, with seven trials reporting attrition rates of more than 10%.

Preventing weight gain

Overall effectiveness

Pooled results across the 12 trials showed that the interventions were effective, with intervention groups gaining significantly less weight than control groups (WMD = −1.19 kg, [95% CI: −1.74, −0.65], $P < 0.0001$).

There was moderate between-study heterogeneity ($\chi^2[11] = 32.03$, $P = 0.0008$; $I^2 = 66\%$). Four trials generated statistically significant effects (Fig. 1), intervention recipients gaining between 2.60 and 7.36 kg less than controls (15,20–22). Eight trials showed no effect on weight gain, although one of these observed a marginally significant negative effect ($P = 0.09$), whereby overweight intervention participants (mean gain 13.6 kg) tended to gain more weight than overweight controls (mean gain 10.1 kg) (17b).

Symmetry in the funnel plot of standard errors suggested that results were not affected by publication bias.

Moderator analyses

Exploratory moderator analyses were run to seek potential covariates of intervention effectiveness based on sample characteristics (pre-pregnancy BMI, gestational age at study entry, proportion of smokers), intervention design and content (whether theory was mentioned, whether a specific diet or PA behaviour was recommended), and characteristics of outcome measurement (timing of follow-up weight measure).

Sample characteristics. There was no moderating effect of pre-pregnancy BMI, although greater weight gain reduction was observed among overweight-only samples

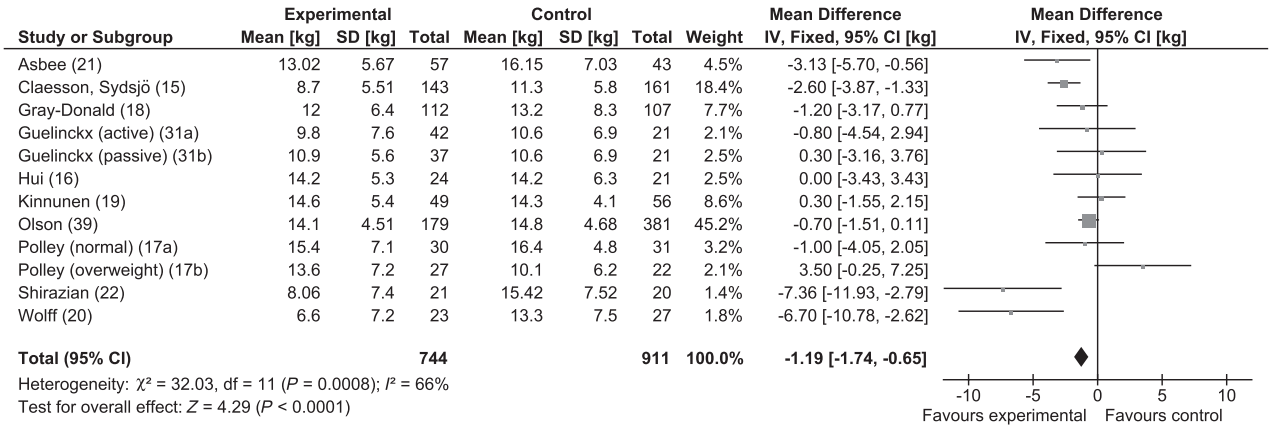

Figure 1 Meta-analysis of effects of behaviour change interventions on gestational weight gain.

(WMD = –2.26 [–3.28, –1.24], $P < 0.0001$) than mixed weight samples (WMD = –0.77 [–1.42, –0.13], $P = 0.02$; Table 3). Gestational age at study entry did not moderate intervention effectiveness, but interventions initiated at or before a mean of 12 weeks were associated with more weight loss (WMD = –1.71 [–2.66, –0.76], $P = 0.0004$) than those after 12 weeks (WMD = –0.94 [–1.60, –0.27], $P = 0.006$).

Three intervention trials undertaken with samples with few (<10%) smokers were effective (WMD = –2.99 [–4.09, –1.90], $P < 0.0001$). Seven trials in which there were 10% or more smokers, and two trials in which smoking status was not reported, showed no effect (WMD = –0.48 [–1.11, –0.16], $P = 0.14$).

Intervention content and delivery. Two trials of interventions purportedly based on theory had no effect on weight gain (WMD = –0.41 [–1.76, 0.95], $P = 0.56$), but the 10 trials not explicitly linked to theory were effective (WMD = –1.35 [–1.94, –0.75], $P < 0.0001$), although considerable heterogeneity was observed in the latter dataset ($\chi^2[9] = 29.29$, $P < 0.0001$; $I^2 = 69\%$).

Seven trials of interventions that reported recommending a specific dietary or PA behaviour to participants showed no overall effect (WMD = –0.59 [–1.58, 0.39]; $P = 0.24$), but five trials in which no behavioural recommendation was specified were effective, although heterogeneity was observed around the mean (WMD = –1.46 [–2.11, –0.80], $P < 0.0001$; $\chi^2[4] = 20.19$, $P < 0.0001$; $I^2 = 80\%$).

A lack of available trials precluded meaningful analyses of the moderating effect of intervention delivery source, or whether the intervention targeted diet alone, or diet and PA behaviour.

Methodological characteristics. There was little difference in weight gain observed in randomized controlled trials (WMD = –1.22 [–2.48, 0.04]) vs. non-randomized trials (WMD = –1.19, [–1.79, –0.58]), but sample size discrepancies rendered the latter effect significant ($P < 0.0001$) and the former non-significant ($P = 0.06$). Validity scores moderated effectiveness, with the five trials scoring at or above the midpoint (≥3) on the validity index more effective (WMD = –2.41 [–3.33, –1.49], $P < 0.0001$; $\chi^2[4] = 7.17$, $P = 0.13$, $I^2 = 44\%$) than the seven trials scoring lower (WMD = –0.53 [–1.21, 0.14], $P = 0.12$; $\chi^2[6] = 14.48$, $P = 0.02$, $I^2 = 59\%$).

The time point at which final weight gain measures were taken appeared related to effectiveness, although in one trial it was unclear when follow-up weight was measured. Four trials which assessed weight gain on the day of delivery were generally effective (WMD = –1.36 [–1.98, –0.73], $P < 0.0001$), but seven trials where weight was assessed prior to the delivery day showed weakened effects (WMD = –0.27 [–1.41, 0.87], $P = 0.65$).

Behaviour change techniques

No behaviour change techniques could be coded in two intervention trials (31a, 31b). Of the remaining 10 codeable intervention trials, on average, 5.1 behaviour change techniques were used per trial (range 3–12). Effective interventions used an average of 4.0 techniques, and ineffective interventions 5.8 techniques, but this difference was not significant ($t[8] = 1.11$, P [two-tailed] = 0.30).

In total, 16 of the 40 techniques described by Michie and colleagues (27) were employed across the 11 interventions. The most commonly used techniques were prompting self-monitoring of behaviour (featured in eight of the 10 codeable intervention trials), provision of feedback on performance (six trials), and setting behavioural goals (five trials). However, each of these techniques was present in effective and ineffective interventions, so no clear patterns emerged (Fig. 2).

Table 3 Moderator analyses: effectiveness of behaviour change interventions on gestational weight gain (in kg) according to study, intervention and measurement characteristics

Variable	Comparisons	Trials included	*n* (intervention)	*n* (control)	Weighted mean difference (kg) (95% CI)	*P*	Heterogeneity	
							χ^2	I^2
Sample characteristics								
Pre-pregnancy BMI	Overweight/obese only	15, 17b, 20, 22, 31a, 31b	293	272	−2.26 (−3.28, −1.24)	<0.0001	21.43***	77%
	Generic	16, 17a, 18, 19, 21, 39	451	639	−0.77 (−1.42, −0.13)	0.02	4.96	0%
Gestational age at study entry	≤12 weeks	15, 19, 22, 31a, 31b	292	279	−1.71 (−2.66, −0.76)	0.0004	13.79**	71%
	>12 weeks	16, 17a, 17b, 18, 20, 21, 39	452	632	−0.94 (−1.60, −0.27)	0.006	16.52**	64%
Proportion of smokers in sample	<10% smokers	15, 20, 21	223	231	−2.99 (−4.09, −1.90)	<0.0001	3.55	44%
	≥10% non-smokers or unknown	16, 17a, 17b, 18, 19, 22, 31a, 31b, 39	521	680	−0.48 (−1.11, 0.16)	0.14	6.39	0%
Intervention characteristics								
Theory mentioned	Yes	18, 19	161	163	−0.41 (−1.76, 0.95)	0.56	1.18	15%
	No	15, 16, 17a, 17b, 20, 21, 22, 31a, 31b, 39	583	748	−1.35 (−1.94, −0.75)	<0.00001	29.29***	69%
Specific (PA or dietary) behaviour recommended	Yes	16, 17a, 17b, 18, 19, 21, 31a	341	301	−0.59 (−1.58, 0.39)	0.24	9.78	39%
	No	15, 20, 22, 31b, 39	403	610	−1.46 (−2.11, −0.80)	<0.0001	20.19***	80%
Intervention target	Diet and PA	15, 16, 17a, 17b, 18, 19, 21, 22, 31a, 31b, 39	721	884	−1.09 (−1.64, −0.54)	<0.0001	24.91**	60%
	Diet only	20	23	27	−6.70 (−10.78, −2.62)	0.001	–	–
Main delivery source	Dietitian	16, 17a, 17b, 18, 20, 21, 31a	315	272	−1.37 (−2.49, −0.26)	0.02	15.61*	62%
	Healthcare workers	19, 39	228	437	−0.54 (−1.28, 0.20)	0.15	0.94	0%
	Midwife	15	143	161	−2.60 (−3.87, −1.33)	<0.0001	–	–
	Unclear	22, 31b	58	41	−2.49 (−5.25, 0.27)	0.08	6.86**	85%
Methodological characteristics								
Trial design	Randomized control trial	16, 17a, 17b, 20, 21, 31a, 31b	240	186	−1.22 (−2.48, 0.04)	0.06	16.42*	63%
	Non-randomized control trial	15, 18, 19, 22, 39	504	725	−1.19 (−1.79, −0.58)	0.0001	15.61**	74%
Study quality score	Score ≥ 3	15, 17a, 18, 21, 22	363	362	−2.41 (−3.33, −1.49)	<0.00001	7.17	44%
	Score < 3	16, 17b, 19, 20, 31a, 31b, 39	381	549	−0.53 (−1.21, 0.14)	0.12	14.48*	59%
Time of follow-up weight measure	Day of delivery	15, 18, 21, 39	491	692	−1.36 (−1.98, −0.73)	<0.0001	8.05*	63%
	Earlier than day of delivery	16, 17a, 17b, 19, 20, 31a, 31b	232	199	−0.27 (−1.41, 0.87)	0.65	14.20**	58%
	Unclear	22	21	20	−7.36 (−11.93, −2.79)	0.002	–	–

Trial numbers correspond to reference list, except: 17a, Polley *et al.*, normal weight groups; 17b, Polley *et al.*, overweight groups; 31a, Guelinckx *et al.*, active intervention; 31b, Guelinckx *et al.*, passive intervention.

*$P < 0.05$, **$P < 0.01$, ***$P < 0.001$.

BMI, body mass index; PA, physical activity.

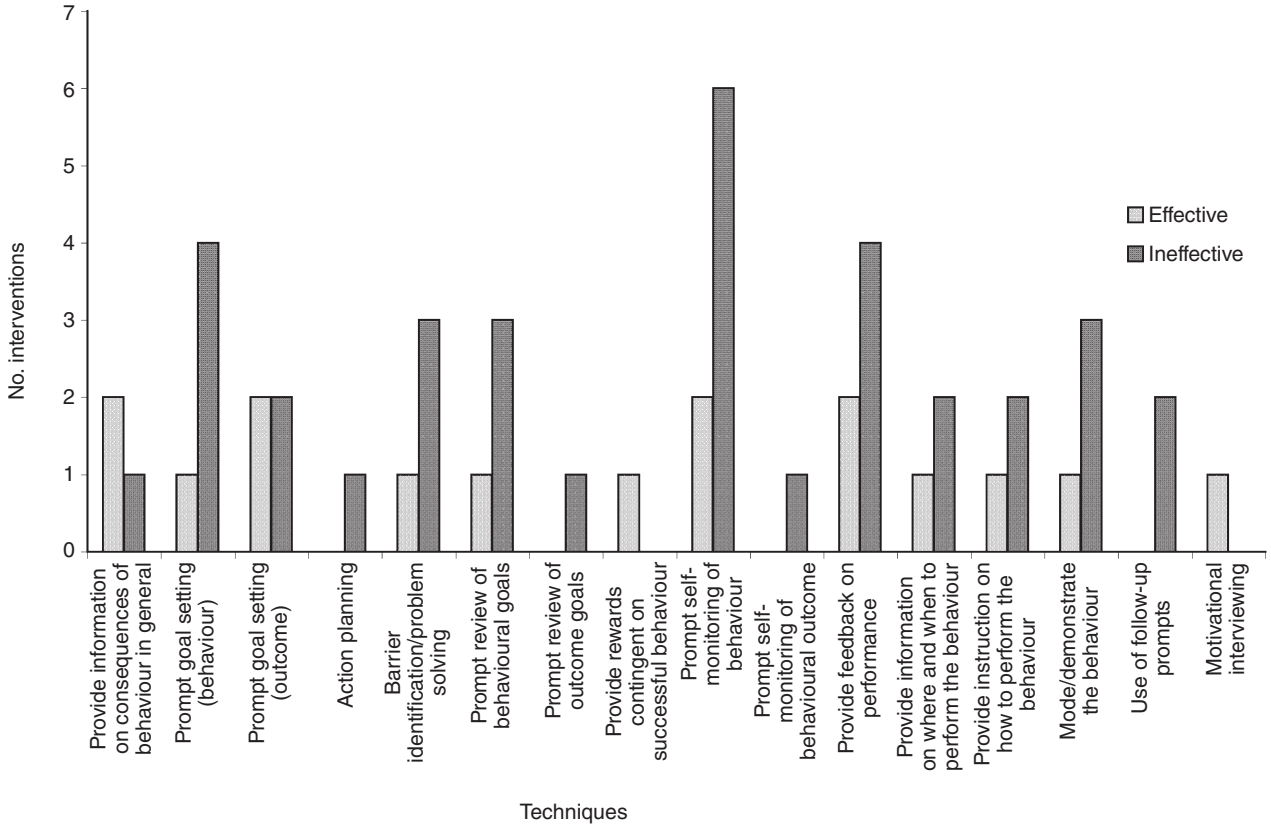

Figure 2 Behaviour change techniques used in gestational weight gain interventions.

Changing behaviour

The six trials that reported intermediate behaviour outcomes found no effects on weight gain. Of these, two showed no effect on diet (17a,17b). One trial showed a positive effect on dietary behaviour but not PA (19), one revealed a positive effect on PA but not diet (16), and two trials found no impact on diet nor PA (31a,31b).

Discussion

Within the recent Institute of Medicine guidelines for weight gain in pregnancy (1), it was noted that 'existing research is inadequate to establish the characteristics of interventions that work reliably to assist women in meeting . . . guidelines for gestational weight gain' (p. 277). Several reviews of behaviour-based dietary or PA interventions designed to limit GWG have been published recently (2,3,12–14), but these have not identified the defining features of effective interventions. Our review sought to deconstruct previous intervention evaluations so as to reveal potential moderators of effectiveness. Meta-analysis of 12 published trials of 11 interventions reported in 10 studies showed that, on average, dietary or PA change programmes produced a small but significant GWG reduction (1.19 kg). In line with previous reviews (2,3,12–14), we observed notable variation in effectiveness, with GWG changes ranging from an increase of 3.50 kg (17b) to a reduction of 7.36 kg (22). Behavioural change was assessed in only six evaluations, none of which observed any effect on GWG. Comparison of effective and ineffective interventions according to changes in behaviour was not therefore possible.

Only two interventions reported using theory to inform intervention design (18,19), and these had less impact on weight outcomes than did interventions which did not report a theory base. This counters evidence suggesting that theory-based interventions are more effective (28). However, given lack of detail regarding how theory was used to develop these two interventions, and underuse of theory in behavioural GWG interventions more generally, it remains unclear whether the 'wrong' theories were used, appropriate theories were poorly applied, or the expected link between use of theory and effectiveness is not always present (25).

Examination of behaviour change techniques can be informative in revealing implicit theoretical assumptions about the underpinnings of expected change (26). Techniques most commonly used were self-monitoring of behaviour, performance feedback and setting goals. This suggests that intervention developers generally conceptual-

ize excessive GWG as a self-regulatory issue, whereby pregnant women are motivated to adopt a healthy diet and increased PA but have problems in revising their behaviour accordingly. The lack of consistent effects for these techniques counters evidence from Michie *et al*.'s recent review of dietary and PA behaviour change interventions within the general population, which found that interventions were typically more effective where self-regulatory techniques are used (24). Michie *et al*.'s review, however, excluded samples of pregnant women, and the assumption that women recognize the need for behaviour change in pregnancy is problematic. Attitudinal research suggests that many pregnant women are indifferent to GWG and may fail to recognize the importance of weight gain restriction (38). Targeting attitudinal and motivational change through, e.g. provision of information about the link between GWG and adverse maternal and neonatal outcomes, or prompting the formation of an intention to act, may be useful alternative routes to changes in diet or PA (13,26). Our coding suggested that information provision has been underused in this literature, although lack of specification in published reports meant that some intervention content (e.g. 'counselling') could not be reliably coded for techniques. Indeed, no behaviour change techniques could be coded in two interventions (31a,31b).

We found no obvious differences in the behaviour change techniques employed between effective and ineffective interventions. This qualifies suggestions from Streuling *et al*.'s recent meta-analytic review that weight monitoring in particular was typically associated with effective interventions (14). The discrepancy between these findings may be understood in light of a distinction between weight monitoring for intervention evaluation purposes vs. for reviewing and informing subsequent behaviour change. Crucial to this distinction is whether participants are informed of their weight, because raising participants' awareness of weight gain may change behaviour: several change techniques relate to such feedback (e.g. providing feedback on performance, giving praise for progress towards weight gain targets, prompting review of weight gain targets or diet and PA plans (26,27)). Not sharing weight information with participants would not be expected to influence behaviour. Streuling *et al*. (14) reported that eight studies (nine trials from the present review) used weight monitoring. We observed behaviour change techniques that could feasibly be linked to weight monitoring (self-monitoring of outcome of behaviour, review of behavioural goals, rewards contingent on performance, feedback on performance) in only six trials (17a,17b,18,19,21,39), of which only two were effective (17a,39). It is therefore premature to suggest that weight monitoring offers an effective behaviour change strategy for GWG reduction purposes.

Sample characteristics and methodological study features were associated with variation in intervention effectiveness. These results require cautious interpretation given the small number of studies available, but nonetheless offer hypotheses for future intervention trials. Interventions were more effective where participants were predominantly non-smokers. This corresponds with research suggesting that health behaviours may cluster, such that engaging in a health-risk behaviour (or failing to engage in a health-protective behaviour) is often associated with engaging in other such behaviours (40). Some commentators have called for interventions to target multiple behaviours simultaneously (40), but we found tentative evidence that recommending a single behavioural change (in dietary intake (20)) resulted in more pronounced GWG minimization than did targeting both diet and PA. However, all seven interventions that specified clear behavioural targets focused on both diet and PA, and had less impact on GWG reduction than interventions in which no specific targets could be coded. Among pregnant women, targeting multiple changes in behaviour concurrently might be unrealistic and may even prompt disengagement from the intervention. Multi-arm GWG reduction trials comparing combined diet and PA interventions with diet or PA-only interventions would be useful in this regard.

From a methodological perspective, we found greater GWG reduction where interventions were initiated earlier, and weight outcomes measured as late as possible, in pregnancy. Potential effects of ostensibly ineffective interventions may have been suppressed due to failures to intervene sufficiently early, or to assess weight gain over the full course of pregnancy. Average GWG reduction was also higher among overweight samples, suggesting that behavioural interventions may be more beneficial when targeted at at-risk women (14). Additionally, where evaluation methods were more robust, in that allocation was concealed where appropriate, intention-to-treat analyses were undertaken to account for attrition, and losses to follow-up were minimized, effect sizes were larger. This emphasizes the importance of limiting design biases when estimating intervention effects.

Our work is qualified by our focus on GWG as a primary outcome of behaviour change interventions in pregnancy; more methodologically rigorous evidence is required to better support the relationship between GWG and maternal and neonatal health outcomes (41). Nonetheless, prenatal care guidelines point to healthy diet and regular PA during pregnancy as ways to limit GWG and so improve mother and child health outcomes (1,11). We adopted a health psychology perspective to explore reasons for mixed effects of dietary and activity-based interventions on GWG. It was not possible to fully exploit our approach in light of the methodology and reporting of existing interventions. Under-reporting of intervention components precludes

accumulation of knowledge regarding the conditions in which behaviour change interventions will reduce GWG. Several recommendations for intervention design, evaluation and reporting arise from this work. First, techniques employed to change behaviour should be specified using standardized definitions (26,27). This would improve communication and permit replication of intervention content. Second, it is useful to assess behavioural outcomes, although we recognize this can be resource-intensive. Third, the anticipated psychological mechanisms underpinning behaviour change should be specified a priori and treated as outcomes. Together, these would facilitate evaluation not only of whether behaviour change has translated into weight gain reduction, but whether an intervention has successfully changed behaviour, and through which psychological pathways this has occurred. Fourth, theory should be consulted more closely to select, apply and evaluate interventions, so as to draw upon scientific knowledge around the causes of behaviour change (42). Guidance for maximizing the utility of theory in this way is available (33). While journal word limits can prohibit publication of some details of intervention content, ensuring that study protocols which specify intervention elements are freely available would aid evidence synthesis (see Smith *et al*. (43)). Designing and reporting interventions in accordance with these principles would help to develop a more robust evidence base, and allow identification of how, when and for whom behavioural interventions in pregnancy reduce GWG.

Conflict of Interest Statement

BG, JW and HC declare that they have no conflicts of interest. LP has received payment from ILSI Europe as reimbursement of expenses incurred in attending a workshop on obese pregnancy and long-term outcomes, and was paid as a member of the Tate and Lyle Research Advisory Group from 2007 to 2010, prior to submission of this work.

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