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Behavioural strategies to reduce obesity among lower socio-economic adults living in high-income countries: a Grades of Recommendation, Assessment, Development and Evaluation-assessed systematic review and meta-analysis of randomised controlled trials

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Abstract

Adult obesity disproportionately affects lower socio-economic groups in high-income countries and perpetuates health inequalities, imposing health and socio-economic burden. This review evaluates the effectiveness of behavioural strategies in reducing weight and cardiovascular disease (CVD) risks among low-income groups based in high-income countries. We searched major databases for randomised controlled trials published between 1 November 2011 and 1 May 2023. Meta-analyses and subgroup analyses were undertaken to analyse the pooled and individual effects of behavioural strategies. Cochrane Risk of bias (RoB 2·0) tool and Grades of Recommendation, Assessment, Development and Evaluation (GRADE) criteria were used to assess the quality and certainty of evidence. Fourteen trials (3618 adults, aged 40·2 ± 9·7 years with BMI 33·6 ± 2·8 kg/m^2) and nine unique interventions were identified. Three trials with high RoB were omitted. Meta-analysis favoured interventions, demonstrating significant reductions in body weight (MD: −1·56 kg, (95 % CI –2·09, −1·03)) and HbA1c (MD: −0·05 %, (95 % CI − 0·10, −0·001)) at intervention end. Sub-group analysis showed no differences in waist circumference, blood pressure or serum lipids. Financial incentives and interactive feedback produced greatest amounts of weight losses ≥ 2 kg (GRADE: moderate). Behavioural strategies are effective weight loss interventions among lower socio-economic groups living in high-income nations. However, the impact on CVD risk remains unclear.

Keywords: **Obesity: Meta-analysis: Clinical nutrition: Low Income**

Obesity affects 13 % of adults worldwide and is a public health concern[1]. In low- and middle-income countries, wealthy people are most affected. However, the reverse holds true in high-income countries[2]. Addressing obesity in high-income countries is crucial since obesity disproportionately affects lower socio-economic groups and perpetuates health inequalities[3,4].

Adult obesity is linked to chronic diseases such as cardiovascular diseases (CVD), diabetes, disability, cancers and raises mortality[5,6]. Chronic illness and weight discrimination limit employment and social prospects, resulting in a vicious cycle of health disparities and lost income[7]. A modest one-kilogram weight loss can lower metabolic risk, delaying disease development[8]. Furthermore, treating obesity complications consumes 8·4 % of a country's health budget[9]. Considering these repercussions and secular trends, reducing obesity is promising in reducing the socio-economic and healthcare burden on society[10].

Low-income people are under-represented in obesity literature[11]. It is hypothesised that the lack of economic and cultural capital hinders engagement in weight loss programmes[12]. Besides, they may achieve poorer behavioural change outcomes following universal treatments according to the 'Inverse Care Law'[13], leading to intervention-generated inequities[14].

Behavioural strategies targeting diet and exercise are the cornerstones of affordable weight management[15]. Existing research on the effectiveness of adult obesity interventions covered strategies such as goal setting with self-monitoring[16], group interventions[17] and personalised feedback[18]. However, lower socio-economic groups were not sampled; thus, findings may not be generalisable. Furthermore, there have been no previous comparisons between various interventions. Technology-based interventions employing webpages, mobile applications or tele-consults were also evaluated but findings were variable with little evidence of long-term efficacy[19,20].

To date, only one review focused on disadvantaged populations[21]; however, studies were outdated, featured middle-income countries and did not examine the impact on

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CVD risk factors. Moreover, the authors included observational studies with poor internal validity. Personalised lifestyle adjustments and community-based nutrition education were beneficial for short-term weight loss, but the authors did not specify strategies for commissioning in future trials. There were no objective pooled assessments available to determine the best interventions. As many trials have been published after this review, this review evaluates current evidence on the effectiveness of behavioural weight loss interventions for low-income populations based in high-income countries. We also examined the effects of weight loss interventions in attenuating CVD risk.

Methods

This review followed Preferred Reporting Items for Systematic Reviews and Meta-Analyses guidelines[22]. The review protocol was registered with PROSPERO (ID: CRD42022331776). No ethical approval was required as no individual patient-level data was sought.

Searches

We searched databases (PubMed, Web of Sciences, Cochrane Central Registry of Controlled Trials and EMBASE) randomised controlled trials (RCT), from November 2011 onwards to 1 February 2022 and re-ran on 1 May 2023. Additional references from previous reviews were screened to retrieve relevant studies. Only publications from November 2011 onwards were selected to provide an updated evidence base from the last review[21].

Keywords and MeSH terms of two main concepts 'weight loss interventions' AND 'low income' were adapted for each database. The search was filtered to adults and RCT published in English. There were no limitations based on sex or sample size. Each study was checked against the World Bank Economic Classifications to confirm it was based in a high-income country. The full search strategy is presented in online Supplementary Materials Table S1.

Eligibility

We considered studies to be eligible for inclusion only if they were RCT with concurrent controls, comprised adult participants (≥ 18 years) and evaluated behavioural interventions on overweight or obese individuals. Surgical and pharmacological treatments were beyond the scope of this meta-analysis. Trials were performed for ≥ 12 weeks (inclusion criterion used in Cochrane to avoid effect size exaggeration). The PICOS (Population, Interventions, Comparators, Outcomes, Study designs) method was used to identify studies in compliance with the eligibility criteria (Table 1).

Data extraction and synthesis

Data relating to source, demographics, interventions and results categorised into primary and secondary outcomes were extracted. Two independent reviewers (PL, YX) independently screened study titles, abstracts and full texts for studies to include. Reviewers (PL, YX) were blinded to each other's decisions. Our screening resulted in 105 papers with a Cohen's kappa of 0·80, indicating high inter-rater reliability between the two reviewers. Any disagreements that surfaced were discussed and resolved by a third reviewer (AW). No individual-level data were sought. Attrition was considered by extracting effects from intention-to-treat analyses. Attempts to obtain missing data from authors were futile.

Risk of bias assessment

Two authors (PL, YX) independently assessed the methodological quality of studies using the Cochrane Risk of Bias (RoB 2·0) tool[23]. Each study was rated on five domains: selection (randomisation and allocation), performance (blinding of observers), attrition (incomplete outcome data), detection (blinding of outcome assessments) and reporting (selection of results). Disagreements were resolved by discussion or consultation with a third author. Studies were classified into: (i) low RoB, all criteria met; (B) some concerns, one or more of the criteria partly met; (C) high RoB, one or more criteria not met (online Supplementary Fig. S1(a)). High RoB studies were excluded from meta-analyses.

For each behavioural intervention strategy, the Grades of Recommendation, Assessment, Development and Evaluation (GRADE) tool was used to assess the certainty of evidence, graded from low to high. Risk of bias, inconsistency (unexplained heterogeneity), indirectness (differences in population, intervention and outcome measures or indirect comparison), imprecision (uncertainty of results) and publication bias were considered[24].

Statistical analyses

All statistical analyses were conducted in Review Manager Version 5.4.1 (Copenhagen: The Nordic Cochrane Centre, The Cochrane Collaboration, 2014). Meta-analyses were conducted for overall effectiveness of behavioural strategies. For specific strategies identified during data extraction, we pooled studies with similar strategies for subgroup analyses. For studies with multi-component interventions, we also identified the key components to perform subgroup analyses for specific distinctive strategies. Only studies with low RoB or of some concerns were pooled.

For three-arm trials (two interventions with one control), intervention groups were combined using the in-built calculator in RevMan by combining the mean and effect size across both interventions to obtain the summary effect size. This is to generate a single pair-wise comparison with overcome unit-of-analysis errors[25]. Studies with multiple publications were reported singularly.

As outcomes were continuous variables measured on the same scale, means and standard deviations (SD) or confidence intervals (CIs) at baseline and end of intervention were extracted to calculate the pooled mean difference (MD) with its 95 % CI, using inverse variance method. Random-effect models were used as heterogeneity was assumed a priori due to the diversity of intervention components and comparator conditions.

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Table 1. Inclusion and exclusion criteria for eligibility of studies

	Inclusion criteria	Exclusion criteria
P	• Focused on adults: Aged 18–65 years old ○ Overweight (BMI ≥ 25 kg/m^2) or ○ Obese (BMI ≥ 30 kg/m^2)* ○ Participants with a low-income background†	• Focused on specific sub-populations: ○ Adults with psychiatric disorders due to reciprocal relationship with obesity[56] ○ Pregnant women as weight reduction is unsafe during gestation[57]. ○ Aged > 65 years old due to survival benefits in obese older adults[58] ○ Involved children and/or adolescents
I	• Lifestyle and behavioural interventions: ○ Trialled in a high-income country as defined by the World Bank economy classifications‡ ○ Interventions ≥ 12 weeks	• Interventions: ○ Trialled in a low/middle-income country as defined by the World Bank economy classifications‡ ○ Involving the use of surgical or pharmacological treatments
C	• Comparator group receiving usual/standard care • Wait-list controls	• Comparator group receiving additional treatment on top of usual/standard care
O	• Primary outcome as defined by mean weight change (kg) from baseline to end of intervention • Secondary outcomes as defined by mean difference in CVD risk factors from baseline to end of intervention: weight circumference (cm), systolic and diastolic blood pressure (mmHg), lipids (mmol/l) and glycaemic profile in HbA1c (%)	• Trials that do not report data on primary outcome (i) mean weight change (kg) from baseline to end of intervention
S	• RCT designed with a single control group • Reporting of original research data	• Secondary analysis of original research data • Economic evaluations • Systematic reviews and meta-analyses • Non-RCT, observational studies, case studies

(i) individual or household annual incomes at or below the federal poverty line[59] or (ii) being in the bottom two quintiles of indices of multiple deprivations (IMD) scores or socio-economic indexes for areas (SEIFA) scores[60,61]
* BMI classifications as defined by the World Health Organisation[1]
† Low income is defined by:
‡ Classifications of countries are based on Gross National Income (GNI) per capita in current USD[62]

Fixed-effect models were not performed due to inter-study differences in participant demographics and settings.

Forest plots were utilised to identify effect estimates and CI. Study heterogeneity was assessed with Cochran's Q tests and I-squared (I^2) statistics, where I^2 of ≤ 25 %, ≤ 50 % and ≤ 75 % correspond to small, moderate and large heterogeneity[26]. The difference in effect between groups was analysed at the 5 % significance level.

We inspected publication bias asymmetries using funnel plots when there were a minimum of 10 studies and ascertained the results by Egger's regression test.

Subgroup and sensitivity analyses

Subgroup analyses were undertaken for sex, intervention duration and BMI as independent moderating variables. Leave-one-out sensitivity analyses were employed to determine the impact of individual studies on the overall effect. If heterogeneity in the meta-analysis was moderate or high, outliers with non-overlapping 95 % CIs were removed. Additionally, for analyses with heterogeneity ≥ 50 %, study characteristics were explored for an explanation. As we aimed to demonstrate the effectiveness of weight loss interventions, high RoB studies were excluded in the meta-analysis as these adversely impacted the heterogeneity of the findings. To address any potential concerns regarding the exclusion of studies without sufficient justification, we have performed sensitivity analyses to demonstrate the robustness of our results (online Supplementary Materials).

Results

The search identified 755 unique publications. 195 duplicates were removed using EndNote (X9) software, and 455 were excluded following title and abstract screening. The remaining 105 papers were screened for full-text eligibility, leaving 14 papers. The screening process and reasons for exclusion are presented in Fig. 1.

Study characteristics

Characteristics of included studies are summarised in online Supplementary Table S2. The final selection of 14 trials included a total of 3618 adults, with a mean age of 40·2 years (SD 9·7) (range: 24·2–53·4 years), and BMI of 33·6 kg/m^2 (SD 2·8) (range: 28·8–38·9 kg/m^2). Studies (n 14) recruited samples from community settings (n 8), primary care settings (n 2), a mixture of community/primary care settings (n 3) or from work sites (n 1). All studies provided evidence for recruiting subjects in lower socio-economic groups.

Trials lasted from 16 weeks to 12 months, with three studies providing further follow-up from 22 weeks to 12 months[27–29]. Controls either received standard/usual care or were wait-listed.

Nine RCT were conducted in the USA[27,28,30–36]. The remaining were conducted in Australia[37,38], Denmark[29], Scotland[39] and the UK[40].

Eight RCT recruited female subjects[27,30–33,36–38] and five with mixed-gender subjects (females > 65 % of the population)[28,29,34,35,40]. One RCT recruited male subjects[39].

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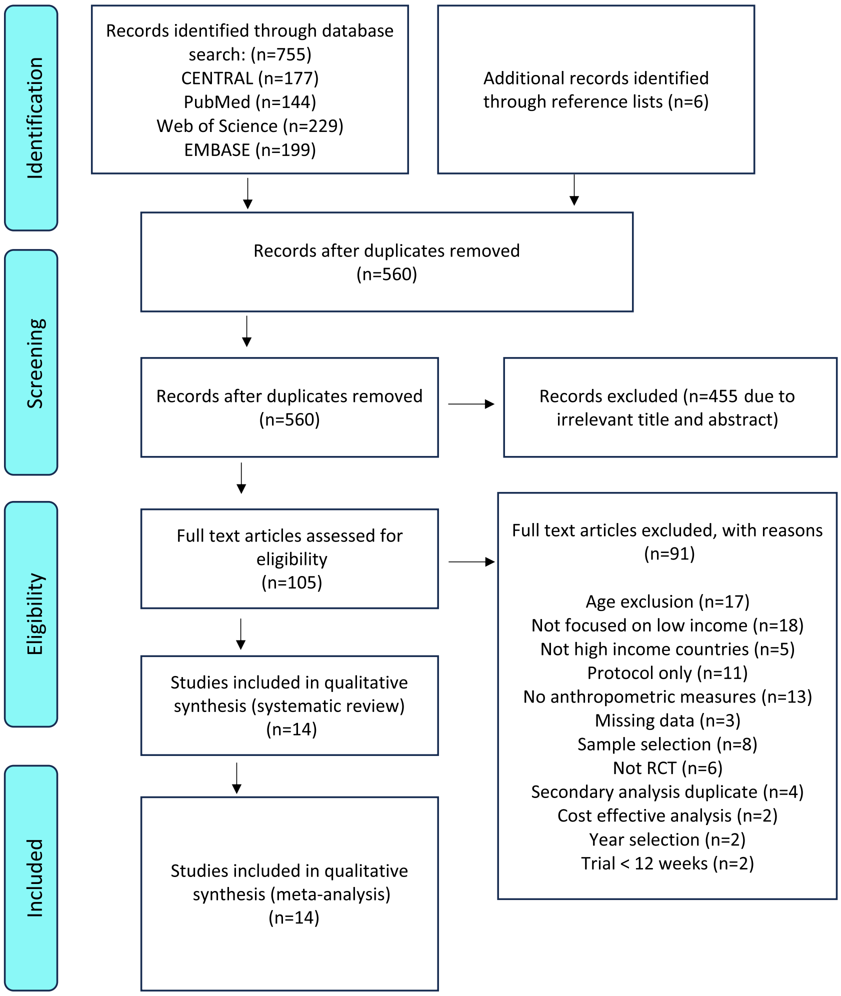

Fig. 1 PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) flowchart of the study selection process

As studies integrated multi-component approaches, they were grouped into nine distinct strategies (CP = Calorie Prescription; DC = Dietary Counselling; FI = Financial Incentives; GS = Goal Setting; IF = Interactive Feedback; LC = Lifestyle Coaching; PA = Physical Activity; SM = Self-Monitoring; SS = Social support).

All studies had one intervention arm with the exception of two studies[28,39]. In five RCT, intervention delivery required in-person attendance[28,32,34,36,40]. Nine studies involved the use of telephone calls, text messages, video conferences, web-based apps or a combination[27,29–31,33,35,37–39]. Attrition varied considerably; from 4–36 % and 0–25 % in intervention and control groups, respectively.

Risk of bias

Three RCT (21 %) had high RoB[29,35,36]. Two studies failed to apply intention-to-treat analyses[29,36]; in one, the attrition rate was > 50 %[29], and in another, controls received lifestyle advice from the centre's nutritionist[36], leading to bias from deviations from intended interventions. Another failed to conceal allocation sequence, risking bias from randomisation[35].

Three RCT were low RoB (21 %)[31,34,38]. Approximately half (57 %)[27,28,30,32,33,37,39,40] had some concerns due to imbalances in group sizes, inadequate descriptions of control treatments, unclear blinding of assessments and possibility of selective reporting (online Supplementary Fig. S1(b)). Due to the nature of the interventions, the lack of participant blinding did not affect RoB.

Primary outcomes

Weight. Studies reporting weight changes from baseline to intervention end were pooled and analysed. After excluding high RoB studies to prevent exaggeration of effect, 11 studies with 2562 participants remained[27,28,30–34,37–40]. Results favoured interventions, demonstrating significant reductions in body weight with moderate heterogeneity (MD: −1·56 kg (95 % CI −2·09, −1·03); $P < 0·001$, $I^2 = 43$ %) (Fig. 2). Leave-one-out sensitivity analyses were performed to identify heterogeneous studies. One outlier was removed[32] due to its large effect size and comparably strong heterogeneity contribution, but results remained robust although effect size was reduced slightly (MD: −1·27 kg (95 % CI −1·69, −0·86); $P < 0·001$ $I^2 = 13$ %) (online Supplementary Fig. S3).

Study or Subgroup	Intervention Mean	Intervention SD	Intervention Total	Control Mean	Control SD	Control Total	Weight	Mean Difference IV, Random, 95% CI
Bennett et al 2013	–1	4.93	97	0·5	4·93	97	9·3%	–1·50 [–2·89, –0·11]
Dombrowski et al 2020	–1·9	2.08	70	–0·86	5·64	35	5·8%	–1·04 [–2·97, 0·89]
Gilmore et al 2017	–0·1	4.02	20	1·8	4·02	20	3·9%	–1·90 [–4·39, 0·59]
Herring et al 2014	–2·9	3.6	9	0·5	2·3	9	3·2%	–3·40 [–6·19, –0·61]
Hutchesson et al 2018	–1·94	4.34	29	0·01	4·36	28	4·6%	–1·95 [–4·21, –0·31]
Lombard et al 2016	–0·48	4.84	348	0·44	4·67	301	17·0%	–0·92 [–1·65, –0·19]
Mayer et al 2019	–1·22	2.9	210	–0·42	2·83	192	19.7%	–0·80 [–1·36, –0·24]
McRobbie et al 2016	–4·2	7.3	221	–2·3	6·6	109	7·9%	–1·90 [–3·47, –0·33]
Phelan et al 2017	–3·2	5.35	174	–0·9	5·69	197	11.9%	–2·30 [–3·42, –1·18]
Rosas et al 2015	–1·65	2.01	166	–0·7	4·75	41	8·5%	–0·95 [–2·44, 0·54]
Samuel-Hodge et al 2013	–3·7	5.5	126	–0·4	4·76	63	8·3%	–3·30 [–4·82, –1·78]
Total (95% CI)			1470			1092	100·0 %	–1·56 [–2·09, –1.03]

Heterogeneity: Tau^2 = 0·29; Chi^2 = 17·44, df = 10 (P = 0·07); I^2 = 43 %
Test for overall effect: z = 5·75 (P < 0·00001)

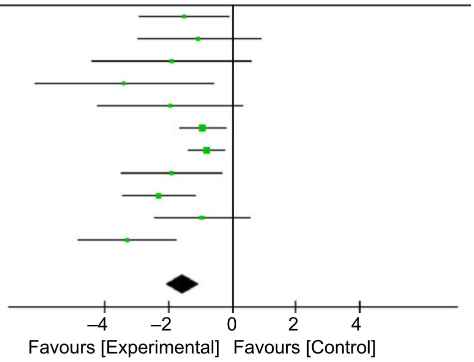

Fig. 2 Forest plot on mean difference in weight changes (kg) from baseline to the end of intervention (Overall effect from all 11 studies)

A slight symmetry was observed on the funnel plot, indicating the possibility of publication bias for the overall summary effect. However, Egger's regression test ($P = 0·32$) ascertained that there was no publication bias.

Secondary outcomes

Glycaemic control. Two RCT (*n* 603)[28,34] demonstrated improvements in HbA1c at end of interventions (MD: –0·05 % (95 % CI –0·10, –0·001); $P = 0·05$, $I^2 = 0$ %) (online Supplementary Fig. S4).

Cardiovascular risk. There were no differences in CVD risk factors such as waist circumference, systolic, diastolic blood pressure and LDL cholesterol (online Supplementary Fig. S5–S8).

Adverse events. No adverse events relating to interventions were documented. For individual intervention strategies and secondary outcomes, funnel plots were not conducted as there were less than ten studies to distinguish true asymmetries.

Overall effect of behavioural strategies

Intervention strategies were evaluated using GRADE criteria with their strength of effect size presented in Table 2. The full assessment is found in online Supplementary Materials Table S3. The forest plots are found in online Supplementary Fig. S9–S17.

All nine strategies were beneficial for weight reduction but only two yielded effect sizes of > 2 kg. Financial incentives in the form of cash vouchers or material goods resulted in the greatest weight reduction (GRADE certainty: moderate)[30–32,39], followed by interactive feedback given through mobile applications, text messages or voice responses (GRADE certainty: moderate)[27,30,31,33].

Three studies incorporated calorie prescriptions[27,31,37]. One trial limited calories to 1800 kilocalories daily,[31] whereas others maintained a daily deficit of 200–600 kilocalories[27,37]. Five studies[27,33,34,37,40] involved dietitians while three studies[28,30,38] recruited community or peer leaders to give comparable effects through regular check-ins with advices on general healthy eating and physical activity information on a weekly to monthly basis (GRADE certainty: low).

Eight studies incorporated physical activity[27,28,31–34,39,40]. Physical activity directives ranged from the use of weights, exercise CDs, group classes, increasing daily steps to at least thirty minutes of physical activity almost daily. Six studies incorporated goal setting where participants made action plans[28,31,33,34,37,40], while seven studies included regular weighs and disbursement of calorie counters, food diaries and fitness trackers as part of self-monitoring[27,30,32,33,37–39].

Seven studies incorporated elements of social support[28,30,32,34,37,38,40]. Group sessions for workouts, cooking demonstrations and nutrition classes were most common. Two hosted private social media groups on Facebook and Instagram[30,37]. Compared with trials without social support (MD: –1·83 kg; (95 % CI –2·29, –1·07); $P < 0·001$, $I^2 = 0$ %), GRADE certainty: moderate), trials incorporating social support demonstrated less weight reduction with moderate heterogeneity ($I^2 = 56$ %, $P = 0·04$).

Subgroup analyses

Subgroup analyses were performed for sex ((online Supplementary Fig. S18), intervention duration online Supplementary Fig. S19) and BMI (online Supplementary Fig. S20) and are presented in Table 3. Females were observed to lose significantly greater weight than males despite similar interventions. Longer interventions lasting 12 months or more were more effective for weight loss, while the extent of weight loss was directly proportional based on the severity of obesity. No further subgroup analyses were undertaken for intervention type as the number of studies is small.

Discussion

This is the first review to use meta-analyses to examine behavioural strategies for weight reduction among adults belonging to lower socio-economic groups. Nine unique strategies were identified. Financial incentives produced the greatest weight reductions with moderate certainty of evidence.

Unlike the previous review conducted by Hllier et al, which focused on interventions that specifically targeted reducing socio-economic inequalities[21] our review aimed to examine the direct effects of interventions to adults belonging to lower socio-

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Table 2. Effect estimate with 95 % CI based on individual intervention function, with GRADE assessment for the certainty of the evidence, relating to weight changes (kg)

Types of intervention	Subjects (studies)	Relative effect with controls (Mean range)	Effect estimate with interventions	95 % CI	Certainty of the evidence (GRADE)
Financial incentives	683 (4 RCT)[30–32,39]	−0·9–0·5 kg	MD – 2·45 kg; $I^2 = 20$ %	−3·37, −1·53	⊕⊕⊕◯ Moderate
Interactive feedback	623 (4 RCT)[27,30,31,33]	−0·9–1·8 kg	MD – 2·09 kg; $I^2 = 0$ %	−2·88, −1·30	⊕⊕⊕◯ Moderate
Calorie prescription	622 (3 RCT)[27,31,37]	−0·9–0·5 kg	MD – 1·98 kg; $I^2 = 40$ %	−2·79, −1·16	⊕⊕⊕◯ Moderate
Self-monitoring	1252 (7 RCT)[28,31,33,34,37,40]	−0·9–1·8 kg	MD – 1·77; $I^2 = 40$ %	−2·58, −0·97	⊕⊕⊕◯ Moderate
Physical activity	1838 (8 RCT)[27,28,31–34,39,40]	−2·3–1·8 kg	MD – 1·63; $I^2 = 50$ %	−2·30, −0·96	⊕⊕◯◯ Low
Social support	1842 (7 RCT)[28,30,32,34,37,40,48]	−2·3–0·5 kg	MD – 1·53; $I^2 = 56$ %	−2·24, −0·82	⊕⊕◯◯ Low
Goal setting	1407 (6 RCT)[28,31,33,34,37,40]	−2·3–1·8 kg	MD – 1·42 kg; $I^2 = 31$ %	−2·06, −0·78	⊕⊕⊕⊕ High
Lifestyle coaching	874 (3 RCT)[28,30,38]	−1·3–0·5 kg	MD – 1·18; $I^2 = 30$ %	−2·13, −0·24	⊕◯◯◯ Very Low
Dietary counselling	1023 (5 RCT)[27,33,34,37,40]	−2·3–1·8 kg	MD – 1·07 kg; $I^2 = 0$ %	−1·54, −0·60	⊕⊕⊕◯ Moderate

Table 3. Subgroup analyses based on sex, intervention duration and BMI, relating to weight changes (kg)

Subgroup analyses	Type /No. of studies	Results	
Sex	Females (*n* 7 studies)	MD: −1·97 kg; $P < 0·001$, $I^2 = 47$ %	−2·74, −1·19
	Males (*n* 1 study)	MD: −1·04 kg; (unable to pool single RCT)	−2·97, 0·89
	Mixed gender (*n* 3 studies)	MD: −0·93 kg; $P = 0·0003$, $I^2 = 0$ %	−1·42, −0·43
Intervention duration	< 12 months (*n* 5 studies)	MD: −1·24 kg; $P < 0·001$, $I^2 = 68$ %	−1·74, −0·75
	12 months or more (*n* 6 studies)	MD: −1·35 kg; $P < 0·00$, $I^2 = 0$ %	−1·83, −0·87
BMI	Overweight (BMI: 25–29·9 kg/m^2) (*n* 2 studies)	MD: −1·02 kg; $P = 0·004$, $I^2 = 0$ %	−1·72, −0·32
	Class I Obese (BMI: 30–34·9 kg/m^2) (*n* 4 studies)	MD: −1·46 kg; $P = 0·0007$, $I^2 = 51$ %	−2·30, −0·62
	Class II Obese (BMI: 35–39·9 kg/m^2) (*n* 5 studies)	MD: −2·01 kg; $P = 0·0001$, $I^2 = 40$ %	−3·03, −0·99

economic groups. Comparing both studies, it was evident that both individual and community weight loss programmes were effective, especially among women, considering the under-representation of men in these studies. Additionally, the regional concentration in the former review prompted us to broaden our search to include studies conducted outside of the USA in our current study.

Overall, results favoured interventions, and the use of behavioural strategies demonstrated a modest, but significant weight loss over controls. Despite the relatively small effect (1·0–2·5 kg), findings are consistent with a recent meta-analysis in predominantly high-income countries where interventions experienced 2·3 kg greater weight loss[41]. Similarly, another meta-analysis showed that a 1 kg weight reduction reduced blood pressure[42], while other trials have utilised a 2 kg weight loss as a clinically meaningful endpoint since it lowers the risk of developing diabetes[43,44].

Despite reductions in HbA1c, other CVD risk factors such as waist circumference, blood pressure and serum lipids showed no improvements. Since many studies did not report these attributes, the relationship between interventions and CVD risk could not be properly evaluated. However, a secondary analysis of subjects participating in the National Health and Nutrition Examination Survey found that low income was associated with CVD risk, underscoring the need to improve weight outcomes in this population[45].

Predictably, there was heterogeneity across the studies identified. Although the meta-analyses provided strong evidence for the overall effectiveness of behavioural strategies, effect sizes varied between strategies. As a consequence, independent investigations were conducted for each strategy through subgroup analyses while exploring differences in sex, intervention duration and BMI classifications.

Compared with a mixed-gender sample, female-targeted interventions produced twice as much weight loss. A recent meta-analysis found no significant differences between gender-targeted studies for weight loss; however, the subjects were restricted to young adults which limited the generalisability of our sample[46]. Another older review found that men lost significantly more weight than women when strategies were restricted to diet and exercise[47]. *As* majority of our cases were females and only one study recruited male subjects[39], the true effect of sex differences could not be determined.

Compared with overweight participants, Class II obese subjects lost twice as much weight whereas Class I obese subjects lost 1·5 times as much weight. Although moderate heterogeneity ($I^2 = 40$ %, $P = 0·15$; $I^2 = 51$ %, $P = 0·11$) was observed, results were insignificant. Findings are consistent with another meta-analysis where comparable subjects (mean BMI range 25–40 kg/m^2) found that severely obese participants shed more weight than their less obese counterparts[48].

Interestingly, participants lost more weight in trials that did not integrate social support. These findings should, however, be interpreted with caution as this subgroup showed greatest heterogeneity when compared with others ($I^2 = 56\,\%$, $P = 0{\cdot}04$). Additionally, it was noted that over the past decade, technology-based interventions have been progressively trialled. With increasing popularity, it is important to ensure equity across socio-economic classes as affordability of computers and smartphones may be a problem[49].

The burden of adult obesity has been studied extensively, and pressure is mounting to halt the growth of obesity in lower socio-economic groups. This is evident with population strategies, such as the USA's Health Equity Resource Toolkit[50] and Australia's National Obesity Strategy 2022–2032[51], highlighting the need to focus on lower socio-economic populations. According to a policy paper, the healthcare system could save £105 million over 5 years if everyone who is overweight or obese, lost 2·5 kg each[52]. Our review builds on this knowledge to form a suite of behavioural strategies to address obesity. However, it is necessary to emphasise that weight reductions are not causal to improving health inequalities; socio-economic determinants of health and the living environment must be considered in addition to weight loss[53].

Implications for research and practice

Longer trials demonstrated weight loss advantages over shorter trials. However, it was not possible to study the fidelity of weight maintenance as few studies recorded follow-up data and the longest follow-up was only one year[28]. As weight regain susceptibility rises 36 weeks post-intervention[54], it is important to consider obesity's chronicity and offer extended support. Notably, although financial incentives resulted in the greatest weight loss of all nine interventions, recent literature suggests that offering incentives for intermediate behavioural improvements, rather than weight reduction *p*er se, may be more beneficial for sustaining weight loss[55]. Overall, this review's favourable findings support the use of behavioural strategies to reduce obesity but future studies should examine their cost-effectiveness.

Strengths and limitations

This review uses strong methodological criteria to synthesise updated, high-quality evidence. To ensure the relevance of the interventions studied and their alignment with technological advancements and digital platforms, we focused exclusively on publications from the last decade. This decision was influenced by the findings of Hilier et al[21], where the interventions primarily consisted of face-to-face nutrition or exercise programmes, except for a single study. In our present study, 64 % of interventions employed tele/video or application-based approaches to engage with participants. This shift towards technology-enabled methods highlights the evolving landscape of intervention strategies. As obesity may be a stigmatising, sensitive issue, only summary data from ethics-approved research were used. All weights and blood results were measured to limit reporting bias. Most intervention strategies (7/9) were of low heterogeneity, giving robust evidence for the strength of effect

Only 21 % of publications were assessed as low RoB. Hence, only studies of low RoB or with some concerns were meta-analysed, while the GRADE tool allows for a pragmatic interpretation of the certainty of evidence. Lack of translation resources limited investigations to English-language publications. Most studies (64 %) were from the USA, thereby limiting the generalisability of findings owing to differences in healthcare systems in other nations. Males were under-represented, and there was inadequate reporting on ethnic diversity. Future reviews should re-evaluate these statistics to identify which targeted interventions are most appropriate. Lastly, this paper could not ascertain if technological interventions were superior to traditional in-person delivery methods due to high heterogeneity.

Conclusion

Behavioural strategies have been shown to be effective in supporting modest, but significant weight loss among individuals with lower socio-economic status living in high-income nations. Of the nine distinct strategies, providing financial incentives resulted in the greatest weight reductions. Few studies explored the relationship between these strategies and CVD risk factors; hence, the impact remains unclear. Although this study advances our understanding of the effectiveness of various intervention strategies, future research should sample a larger population that is reflective of the population's diversity. Comparative analyses should also be conducted on the cost-effectiveness of these strategies to determine the economic credentials of interventions.

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Supplementary material

For supplementary material/s referred to in this article, please visit https://doi.org/10.1017/S0007114523001940

References

1. WHO (2021) *Obesity and Overweight*. Geneva: WHO.
2. Kim TJ & von dem Knesebeck O (2018) Income and obesity: what is the direction of the relationship? A systematic review and meta-analysis. *BMJ Open* **8**, e019862.

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3. Bentley RA, Ormerod P & Ruck DJ (2018) Recent origin and evolution of obesity-income correlation across the United States. *Palgrave Comm* **4**, 146.
4. Templin T, Tiago COH, Thomson B, *et al.* (2019) The overweight and obesity transition from the wealthy to the poor in low- and middle-income countries: a survey of household data from 103 countries. *PLoS Med* **16**, e1002968.
5. Stringhini S, Carmeli C, Jokela M, *et al.* (2017) Socioeconomic status and the 25 × 25 risk factors as determinants of premature mortality: a multicohort study and meta-analysis of 1·7 million men and women. *Lancet* **389**, 1229–1237.
6. Ameye H & Swinnen J (2019) Obesity, income and gender: the changing global relationship. *Global Food Secur* **23**, 267–281.
7. Wimalawansa SJ (2014) Stigma of obesity: a major barrier to overcome. *J Clin Transl Endocrinol* **1**, 73–76.
8. Morris E, Jebb SA, Oke J, *et al.* (2021) Effect of weight loss on cardiometabolic risk: observational analysis of two randomised controlled trials of community weight-loss programmes. *Br J General Pract* **71**, e312–e9.
9. OECD OfEC-oaD. The Heavy Burden of Obesity 2019. https://www.oecd.org/health/the-heavy-burden-of-obesity-67450d67-en.htm (Accessed April 2022).
10. Peeters A & Backholer K (2015) Reducing socioeconomic inequalities in obesity: the role of population prevention. *Lancet Diabetes Endocrinol* **3**, 838–840.
11. Harvey JR & Ogden DE (2014) Obesity treatment in disadvantaged population groups: Where do we stand and what can we do? *Prev Med* **68**, 71–75.
12. Pampel FC, Krueger PM & Denney JT (2010) Socioeconomic disparities in health behaviors. *Ann Rev Sociol* **36**, 349–370.
13. Watt G (2002) The inverse care law today. *Lancet* **360**, 252–254.
14. White M, Adams J, Heywood P, *et al.* (2009) Social Inequality and Public Health. How and Why do Interventions that Increase Health Overall Widen Inequalities within Populations? Bristol: Policy Press. pp. 65–81.
15. Olateju IV, Ogwu D, Owolabi MO, *et al.* (2021) Role of behavioral interventions in the management of obesity. *Cureus* **13**, e18080-e.
16. Willmott TJ, Pang B, Rundle-Thiele S, *et al.* (2019) Weight management in young adults: systematic review of electronic health intervention components and outcomes. *J Med Internet Res* **21**, e10265.
17. Robertson C, Avenell A, Stewart F, *et al.* (2017) Clinical effectiveness of weight loss and weight maintenance interventions for men: a systematic review of men-only randomized controlled trials (The ROMEO Project). *Am J Men's Health* **11**, 1096–1123.
18. Sherrington A, Newham JJ, Bell R, *et al.* (2016) Systematic review and meta-analysis of internet-delivered interventions providing personalized feedback for weight loss in overweight and obese adults. *Obes Rev* **17**, 541–551.
19. Jahangiry L & Farhangi MA (2021) Obesity paradigm and web-based weight loss programs: an updated systematic review and meta-analysis of randomized controlled trials. *J Health Popul Nutr* **40**, 1–8.
20. Hartmann-Boyce J, Jebb SA, Fletcher BR, *et al.* (2015) Self-help for weight loss in overweight and obese adults: systematic review and meta-analysis. *Am J Public Health* **105**, e43–e57.
21. Hillier-Brown FC, Bambra CL, Cairns JM, *et al.* (2014) A systematic review of the effectiveness of individual, community and societal-level interventions at reducing socio-economic inequalities in obesity among adults. *Int J Obes* **38**, 1483–1490.
22. Page MJ, McKenzie JE, Bossuyt PM, *et al.* (2021) The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. *BMJ* **372**, n71.
23. Sterne JAC, Savović J, Page MJ, *et al.* (2019) RoB 2: a revised tool for assessing risk of bias in randomised trials. Br Med J 366, l4898.
24. Guyatt GH, Oxman AD, Vist GE, *et al.* (2008) GRADE: an emerging consensus on rating quality of evidence and strength of recommendations. *BMJ* **336**, 924–926.
25. Higgins J, Thomas J, Chandler J, *et al.* (2021) Cochrane Handbook for Systematic Reviews of Interventions Version 6.2 (updated February 2021). Cochrane; 2021. www.training.cochrane.org/handbook (Accessed July 2022).
26. Higgins J, Thompson S, Deeks J, *et al.* (2003) Measuring inconsistency in meta-analyses. *Br Med J* **327**, 557–560.
27. Balk-Moller NC, Poulsen SK & Larsen TM (2017) Effect of a nine-month web- and app-based workplace intervention to promote healthy lifestyle and weight loss for employees in the social welfare and health care sector: a randomized controlled trial. *J Med Internet Res* **19**, e108.
28. Bennett GG, Foley P, Levine E, *et al.* (2013) Behavioral treatment for weight gain prevention among black women in primary care practice: a randomized clinical trial. *JAMA Intern Med* **173**, 1770–1777.
29. Rosas LG, Thiyagarajan S, Goldstein BA, *et al.* (2015) The effectiveness of two community-based weight loss strategies among obese, low-income US Latinos. *J Acad Nutr Dietetics* **115**, 537–U300.
30. Bennett GG, Steinberg D, Askew S, *et al.* (2018) Effectiveness of an app and provider counseling for obesity treatment in primary care. *Am J Prev Med* **55**, 777–786.
31. Gilmore LA, Klempel MC, Martin CK, *et al.* (2017) Personalized mobile health intervention for health and weight loss in postpartum women receiving women, infants, and children benefit: a randomized controlled pilot study. *J Womens Health* **26**, 719–727.
32. Herring SJ, Cruice JF, Bennett GG, *et al.* (2014) Using technology to promote postpartum weight loss in urban, low-income mothers: a pilot randomized controlled trial. *J Nutr Educ Behav* **46**, 610–615.
33. Mayer VL, Vangeepuram N, Fei K, *et al.* (2019) Outcomes of a weight loss intervention to prevent diabetes among low-income residents of East Harlem, New York. *Health Educ Behav* **46**, 1073–1082.
34. Phelan S, Hagobian T, Brannen A, *et al.* (2017) Effect of an internet-based program on weight loss for low-income postpartum women: a randomized clinical trial. *J Am Med Assoc* **317**, 2381–2391.
35. Samuel-Hodge CD, Garcia BA, Johnston LF, *et al.* (2013) Translation of a behavioral weight loss intervention for mid-life, low-income women in local health departments. *Obesity* **21**, 1764–1773.
36. Van Name MA, Camp AW, Magenheimer EA, *et al.* (2016) Effective translation of an intensive lifestyle intervention for Hispanic women with prediabetes in a community health center setting. *Diabetes Care* **39**, 525–531.
37. Hutchesson MJ, Callister R, Morgan PJ, *et al.* (2018) A targeted and tailored eHealth weight loss program for young women: the be positive be Healthe randomized controlled trial. *Healthcare* **6**, 39.
38. Lombard C, Harrison C, Kozica S, *et al.* (2016) Preventing weight gain in women in rural communities: a cluster randomised controlled trial. *PLoS Med* **13**, e1001941.
39. Dombrowski SU, McDonald M, van der Pol M, *et al.* (2020) Game of stones: feasibility randomised controlled trial of how to engage men with obesity in text message and incentive interventions for weight loss. *BMJ Open* **10**, e032653.
40. McRobbie H, Hajek P, Peerbux S, *et al.* (2016) Tackling obesity in areas of high social deprivation: clinical effectiveness and

cost-effectiveness of a task-based weight management group programme – a randomised controlled trial and economic evaluation. *Health Technol Assessment* **20**, 1–150.

41. Madigan CD, Graham HE, Sturgiss E, *et al.* (2022) Effectiveness of weight management interventions for adults delivered in primary care: systematic review, meta-analysis of randomised controlled trials. Br Med J 377, e069719-e.
42. Neter JE, Stam BE, Kok FJ, *et al.* (2003) Influence of weight reduction on blood pressure. *Hypertension* **42**, 878–884.
43. Stevens VJ, Obarzanek E, Cook NR, *et al.* (2001) Long-term weight loss and changes in blood pressure: results of the trials of hypertension prevention, phase II. *Ann Intern Med* **134**, 1–11.
44. Clark DO, Keith N, Weiner M, *et al.* (2019) Outcomes of an RCT of videoconference *v.* in-person or in-clinic nutrition and exercise in midlife adults with obesity. Obes Sci Pract 5, 111–119.
45. Seligman HK, Laraia BA & Kushel MB (2010) Food insecurity is associated with chronic disease among low-income NHANES participants. *J Nutr* **140**, 304–310.
46. Sharkey T, Whatnall MC, Hutchesson MJ, *et al.* (2020) Effectiveness of gender-targeted *v.* gender-neutral interventions aimed at improving dietary intake, physical activity and/or overweight/obesity in young adults (aged 17–35 years): a systematic review and meta-analysis. *Nutr J* **19**, 1–20.
47. Williams RL, Wood LG, Collins CE, *et al.* (2015) Effectiveness of weight loss interventions – is there a difference between men and women: a systematic review. *Obes Rev* **16**, 171–186.
48. Barte JC, Veldwijk J, Teixeira PJ, *et al.* (2014) Differences in weight loss across different BMI classes: a meta-analysis of the effects of interventions with diet and exercise. *Int J Behav Med* **21**, 784–793.
49. Ashrafian H, Toma T, Harling L, *et al.* (2014) Social networking strategies that aim to reduce obesity have achieved significant although modest results. *Health Affairs* **33**, 1641–1647.
50. CDC CfDCaP (2021) Health Equity Resource Toolkit for State Practitioners Addressing Obesity Disparities. https://www.cdc.gov/nccdphp/dnpao/health-equity/state-health-equity-toolkit/index.html (accessed April 2022).
51. Australia Co (2022) National Obesity Strategy 2022–2032. Enabling Australians to eat well and be active. Health Ministers' Meeting. https://www.health.gov.au/sites/default/files/documents/2022/03/national-obesity-strategy-2022-2032_0.pdf (accessed June 2022).
52. UK Government (2020) Policy Paper. Tackling obesity: Empowering Adults and Children to live Healthier Lives. Department of Health and Social Care. https://www.gov.uk/government/publications/tackling-obesity-government-strategy/tackling-obesity-empowering-adults-and-children-to-live-healthier-lives (accessed June 2022).
53. Borys J-M, Richard P, Ruault Du Plessis H, *et al.* (2016) Tackling health inequities and reducing obesity prevalence: the EPODE community-based approach. *Ann Nutr Metab* **68**, 35–38.
54. Machado AM, Guimarães NS, Bocardi VB, *et al.* (2022) Understanding weight regain after a nutritional weight loss intervention: systematic review and meta-analysis. *Clin Nutr Espen* **49**, 138–153.
55. Jay M, Orstad SL, Wali S, *et al.* (2019) Goal-directed *v.* outcome-based financial incentives for weight loss among low-income patients with obesity: rationale and design of the Financial Incentives foR Weight Reduction (FIReWoRk) randomised controlled trial. *BMJ Open* **9**, e025278.
56. Luppino FS, De Wit LM, Bouvy PF, *et al.* (2010) Overweight, obesity, and depression. *Arch Gen Psychiatry* **67**, 220.
57. NICE NIfHaCE (2021) Weight Management Before, During, and After Pregnancy (PH27). https://www.nice.org.uk/guidance/ph27 (accessed August 2022).
58. Donini LM, Pinto A, Giusti AM, *et al.* (2020) Obesity or BMI paradox? Beneath the tip of the iceberg. *Front Nutr* **7**, 53.
59. ASPE OotASfPaE (2021) Poverty Guidelines Services USDoHaH. https://aspe.hhs.gov/topics/poverty-economic-mobility/poverty-guidelines (accessed January 2023).
60. ABS ABoS Socio-Economic Indexes for Areas (SEIFA) 2016 Technical Paper. ABS Catalogue No 20330550012018. pp. 1–39. https://www.intelia.com.au/wp-content/uploads/2020/09/SEIFA-2016-Technical-Paper.pdf (accessed July 2022).
61. UK Government (2019) The English Indices of Deprivation 2019 (IoD2019). Ministry of Housing CLG. September 2019 ed. London. pp. 1–31. https://www.gov.uk/government/collections/english-indices-of-deprivation (accessed July 2022).
62. World Bank (2021) World Bank Country and Lending Groups. https://datahelpdesk.worldbank.org/knowledgebase/articles/906519-world-bank-country-and-lending-groups (accessed July 2022).