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Effective Behavior Change Techniques for Successful Weight Loss and Weight Loss Maintenance Among Adults With Overweight and Obesity: A Systematic Review and Meta-Analysis

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ABSTRACT

Achieving and maintaining weight loss are challenging and require sustained lifestyle changes. This study examined which behavior change techniques (BCTs) support long-term weight outcomes among adults with overweight or obesity. We synthesized evidence from randomized controlled trials of behavioral interventions versus control or alternative interventions, focusing on nonclinical adults (BMI > 25) with ≥ 6-month follow-up, published between 2010 and 2025, that reported weight outcomes. Sixty-five studies (approximately 10,000 participants) evaluating 87 behavioral interventions targeting physical activity, diet, or both were included. BCTs were coded using the BCT Taxonomy v1. Meta-analysis estimated pooled effects on total weight loss (baseline to follow-up) and weight maintenance (posttreatment to follow-up). Behavioral interventions produced a mean effect size for total weight loss of Hedges' $g = -0.19$ (95% CI = −0.30 to −0.13), equating to an average additional weight loss of approximately 3.25 kg compared to controls. No significant effect was found for weight maintenance after initial loss, indicating no statistically significant difference in weight change between intervention and control groups during follow-up. Meta-regression examined the number of BCTs, intervention type, and follow-up duration, but none significantly moderated effects. Subgroup analyses identified the following effective BCTs: goal setting, feedback on behavior and outcome(s) of behavior, self-monitoring of behavior and outcome(s) of behavior, instruction on how to perform the behavior, demonstration of the behavior, conserving mental resources and incentives. These BCTs appear to support relative long-term weight outcomes and warrant further investigation.

1 | Introduction

Overweight (body mass index (BMI) > 25) and obesity (BMI > 30) are highly prevalent among adults worldwide: in 2022 an estimated 2.5 billion adults overweight (43%), of whom 16% were obese. Obesity contributes to over 200 health conditions among which are cardiovascular disease, type 2 diabetes, and cancer [1, 2]. Increasingly, obesity is recognized as a chronic, relapsing, noncommunicable disease [2]. Obesity is a complex multifactorial disease characterized by chronic dysregulation of energy balance, resulting from a sustained mismatch between energy intake and energy expenditure. This dysregulation is shaped by the interaction between biological susceptibility, including neuro-endocrine and metabolic regulation, dietary behavior and physical activity, and broader environmental and societal factors, such as food availability, marketing and pricing and policy contexts [3, 4].

Even modest weight loss can yield important health benefits, including reductions in cardiovascular risk factors [5], and

lowering the risk of certain cancers (e.g., Yates et al. [6]). While behavioral interventions can successfully induce short-term weight loss, many people struggle to maintain weight loss and often regain weight even when interventions are well designed and adherence is high [7]. Importantly, even sustained effort frequently fails to prevent weight regain, and behavioral interventions typically yield small effects that attenuate over time when assessed across multiple years [8]. This limited durability is partly explained by biological adaptations that occur following weight loss, which promote weigh regain. After weight reduction, changes in appetite-regulating hormones, energy expenditure, and neurobiological reward pathways promote increased hunger and reduced metabolic rate, effects that may persist for years [4]. As a result, weight regain is common even among individuals who continue to engage in health-promoting behaviors. Behavioral strategies therefore operate within biological constraints that actively promote weight regain, limiting the magnitude and durability of intervention effects. Sustained weight-loss maintenance, and thus effective long-term obesity management, requires ongoing effort [9].

An earlier systematic review and meta-analysis by Dombrowski and colleagues has shown that behavioral interventions can contribute to small, but persistent weight differences over time [10]. Generally, behavior change interventions are complex multi-component approaches offering a great variety of intervention types, targeting different behavioral factors such as knowledge, motivation, skills, and self-efficacy, using different delivery formats (including face-to-face or online, individual or group setting, and digital apps), based on different theoretical models (such as the health belief model, theory of planned behavior, or the self-determination theory) [11–13] and/or the different behavior change techniques (BCTs) they employ. A BCT is defined as "an observable, replicable and irreducible component of an intervention designed to alter or redirect causal processes that regulate behaviour" [14]. Importantly, within the context of obesity as a chronic, relapsing disease, BCTs should not be viewed as mechanisms that can fully counteract the biological adaptations promoting weight regain. Rather, specific BCTs may support individuals in sustaining behavioral changes for longer, help attenuate the rate or magnitude of weight regain, or contribute to clinically meaningful differences in weight outcomes relative to comparison conditions. Although Dombrowski et al. [10] demonstrated that behavioral interventions can lead to small but persistent weight differences over time; they did not examine which specific BCTs contributed to long-term weight loss maintenance. However, they underscored that to bridge the gap between behavior change and behavioral maintenance, it is essential to understand which (combination of) BCTs should be employed in interventions [15]. Previously the BCTs "Feedback on behaviour," "Goal setting," and "Graded tasks" were associated with initial weight loss [16, 17]. However, it remains unclear whether particular BCTs support longer-term weight loss [18]. Understanding which BCTs in behavioral interventions contribute to both (1) initial weight loss and (2) a maintained weight loss may help clarify the role and limitations of behavioral intervention components in obesity management.

Michie et al. developed a behavior change technique taxonomy (BCTT v1), which is an instrument that can be used to evaluate and decode the content of behavior change interventions, examining its unique BCTs [19]. The taxonomy consists of 93 different BCTs. The BCTT v1 and predecessors have been successfully applied in various meta-analytic reviews in order to understand which BCTs in interventions are effective, for instance in domains of physical activity, dietary intake, or alcohol consumption [10, 14, 18–20].

Some meta-analyses have examined the long-term effects of BCTs. For instance, Samdal and colleagues examined BCTs in the context of physical activity and diet among adults with obesity [21]. They found an overall effect size of 0.24, with as most effective BCTs "goal setting," and "provision of feedback on behaviour." Additionally, Carraça et al. carried out a systematic review and meta-analysis on effective BCTs to promote physical activity in adults with overweight or obesity [22]. However, these studies did not explicitly look at weight, nor at long-term weight maintenance. Furthermore, Avery et al. examined physical activity and improvement of glycemic control among people with diabetes type 2 [23]. They found that BCTs promoting physical activity differed from BCTs that were associated with the health outcome (i.e., improved glucose control [HbA1c]).

In sum, (1) specific BCTs may promote long-term behavioral effects, and these may differ from BCTs promoting short-term effects, and (2) BCTs may have different effects on behavioral outcomes (e.g., diet or physical activity) and health outcomes (i.e., weight or BMI), and effects on behavior do not necessarily translate into sustained changes in weight. As far as we know, no meta-analytic study examined the effectiveness of BCTs on weight loss maintenance (i.e., the maintenance of posttreatment weight loss until follow-up), which is the primary health outcome for people with obesity.

In the present study, we examined which BCTs effectively contribute to weight loss and weight loss maintenance among adults with overweight and obesity, using the BCTTv1.

Our objectives were to answer the following research questions:

1. Do behavioral weight-loss interventions result in relative long-term differences in weight outcomes compared with control conditions?
2. Do participants in the intervention groups maintain weight loss at the long-term follow-up relative to comparison conditions?
3. Are there specific BCTs associated with differences in long-term weight loss or weight loss maintenance effects?

2 | Methods

This systematic review and meta-analysis examined the effectiveness of weight-loss interventions that incorporated identifiable BCTs. We evaluated the effect of behavioral weight-loss interventions on long-term weight loss (defined as of weight change from baseline to follow-up), and specifically weight-loss maintenance (i.e., weight change from posttreatment to follow-up) compared to control conditions in nonclinical populations (i.e., individuals with overweight or obesity without

comorbidities). Given that most adults tend to regain weight within 6 months after initial loss [7, 24], long-term follow-up in this review was defined as ≥6 months after intervention. In addition, we explored which individual BCTs were associated with sustained weight-loss effects. We followed guidelines from PICO, PRISMA, and TIDieR [25]. The eligibility criteria handled for inclusion of the studies are presented in Table 1.

2.1 | Eligibility Criteria

The eligibility criteria handled for inclusion of the studies are presented in Table 1. Eligibility criteria included behavioral interventions for adults with overweight or obesity (18–64 years, BMI > 25) that aimed to promote physical activity, a healthy diet (e.g., increasing fruit and vegetable intake, decreasing caloric intake or both) and/or weight loss in randomized controlled trials (RCTs). Interventions did not have to focus on specifically on weight loss, and they could target dietary or sedentary behavior. However, they needed to report outcome measures with sufficient statistics using standardized or validated measures for weight (e.g., in pounds or kilograms) to allow for calculation of a standardized effect size for the intervention. Interventions could focus on weight loss, weight-loss maintenance, or both. Besides, interventions needed to specify behavioral techniques or methods, which could be classified as BCTs (e.g., goal setting, self-monitoring or action planning) [19]. Interventions targeting clinical populations with medical problems or patients (e.g., chronically ill patients, adults experiencing mental health problems, and stroke or cancer survivors) were excluded. Interventions concerning several modes of delivery (including face-to-face, eHealth, group, or individual) were included.

TABLE 1 | Eligibility criteria (PICO, design, setting, and time frame) of studies included in the meta-analytic review.

Eligibility criteria	
Participants	Nondiagnosed adults (18–64 years) including at-risk populations (overweight and obese, not chronically ill adults)
Interventions	Nonsurgical physical activity, dietary & weight loss interventions (including e-Health, community-based, family-based or face-to-face interventions) BCTs
Comparison	Control group including care as usual and waitlist control or a less intense intervention or an intervention with different content.
Outcomes	Weight (loss)
Study design	RCTs (randomized controlled trials) with follow-up measure after 6 months from baseline
Time frame	Articles published between 2010 and November 2025

2.2 | Search Method

Scopus and Web of Science were searched from March to April 2020 for peer-reviewed journal articles written in English (published between 2010 and 2020) using a Boolean search strategy as described in van der Ploeg et al. and in Versluis et al. [26, 27]. The search strategy can be found in Appendix 1. This resulted in 1089 articles. In December 2021 and November 2025, additional searches were carried out to keep the meta-analysis up to date; this resulted in a total of 407 extra articles. In a sample of 30 titles screened independently by two reviewers (R.A. and K.P.), there was 93% agreement on exclusion. Disagreements were resolved through discussion and consulting with a third reviewer (P.v.E.).

2.3 | Coding of Study Characteristics and BCTs

Studies were coded according to the TIDieR checklist by three authors (R.A., K.P., and I.E.) [25]. The following information was extracted per study: (a) bibliographic information, (b), location (country), (c) type of behavior targeted by intervention (healthy diet, physical activity or both), (d) participant information (e.g., general description, age, gender, ethnicity, and sample size), (e) intervention information (name and intervention focus; i.e., weight loss intervention, weight maintenance intervention or both, BCTs used, number of contacts, duration of intervention, format of delivery, source of delivery, type of control group; i.e., waitlist, usual care, minimal intervention or active intervention, length of follow-up, and setting), (f) methodological information (study duration; i.e., time between baseline and last follow-up, attrition, outcomes in weight loss per group, and follow-up duration; i.e., time between posttreatment and last follow-up, study design, and randomization), and effect size information (mean, standard deviation, and number of responders).

BCTs were coded using the BCT Taxonomy v1 (BCTTv1) [19]. BCTs included the categories (1) goals and planning, (2) feedback and monitoring, (3) social support, (4) shaping knowledge, (5) natural consequences, (6) comparison of behavior, (7) associations, (8) repetition and substitution, (9) comparison of outcomes, (10) reward and threat, (11) regulation, (12) antecedents, (13) identity, (14) scheduled consequences, (15) self-belief, and (16) covert learning. Interreliability checks on identification of techniques were conducted by R.A. and K.P. on six studies (i.e., 6 of 65 included studies, 10%) that collectively held 13 intervention and control conditions to rate. Mean κ value was 0.71 suggesting substantial agreement; however, κ ranged between 0 and 1 over the separate BCTs. κ was below moderate (< 0.40) for BCT 1.7 ("Review outcome goals"), BCT 7.1 ("Prompts/cues"), BCT 8.7 ("Graded tasks"), and BCT 12.5 ("Adding objects to the environment"), κ was almost perfect (> 0.80) for BCT 1.4 ("Action planning"), BCT 1.5 ("Review behavioural goal(s)"), BCT 2.3 ("Self-monitoring of behaviour"), BCT 2.4 ("Self-monitoring of outcome(s) of behaviour"), BCT 2.7 ("Feedback on outcome(s) of behaviour"), BCT 4.1 ("Instruction on how to perform the behaviour"), BCT 6.1 ("Demonstration of the behaviour"), BCT 10.7_10.8 ("(Self) incentive"), BCT 10material ("Material reward & material incentive"), and BCT 10social ("Social reward & social incentive"). When interrater agreement was low, as indicated by a low κ coefficient, a third author (P.v.E.) was consulted to resolve discrepancies, and the rating instructions

were subsequently clarified to improve consistency and prevent future disagreements. In some cases, BCT categories were grouped because of there being too few studies employing a certain BCT as well as challenges regarding reporting and coding BCTs such as "social support" where all types of social support were coded as BCT 3 [28].

2.4 | Assessment of Bias and Study Quality

Risk of bias was assessed using the Cochrane Risk of Bias tool to evaluate internal validity of eligible RCTs based on study and outcome level [29]. Criteria assessed include randomization generation, allocation concealment, blinding of outcome assessors, blinding participants and personnel, completeness of outcome data (i.e., withdrawals), selective outcome reporting, and "other" risks of bias. For this review, blinding of outcome assessors was evaluated positively if weight was not self-reported but collected by objective measures, such as using a digital scale, mostly taken by study personal. Furthermore, performance bias was checked by assessing fidelity of the intervention implementation, by, for example, means of monitoring of intervention implementation, observations, assessment, or coding and evaluation of execution. Risk of bias was checked by three authors (R.A., I.E., and K.P.). Data of scoring reviewers was compared and discussed in case of any discrepancies. In case of nonresolution, another author (P.v.E.) was consulted.

3 | Statistical Analysis

3.1 | Effect Size Calculations

Summary statistics for weight in kilograms were extracted for all reported time points to calculate two types of effect sizes: the study arm effect size and between group effect size. Study arm effect sizes were calculated as the weight change within a study arm (i.e., control group or intervention group) as a function of the standard deviation of the premeasurement [30]. The between group effect size was obtained as the reported adjusted effect size (Cohen's d) or the adjusted unstandardized regression coefficient with the standard deviation of the outcome. If these were missing, other statistics were used to compute the between group effect size (e.g., means and standard deviations or mean change and standard error). The standardized mean differences (SMDs) were calculated using Hedges' g to express the difference between the means for the intervention and control group in standard deviation units. To determine the effect of interventions on long-term weight loss as well as weight maintenance, the SMD was computed for the total weight loss effect (i.e., last follow-up vs. baseline) and the weight maintenance effect, specifically, (i.e., follow-up vs. posttreatment). In studies where the control group was compared to multiple interventions, we adjusted the sample size of the control group so that each participant was only used once as a comparison.

3.2 | Meta-Analysis

The study arm effects were used to visualize the effect sizes over all time-points, whereas the between group effects were used in the random effects meta-analyses. As we anticipated considerable between-study heterogeneity, a random-effects model was used to pool effect sizes. The restricted maximum likelihood estimator was used to calculate the heterogeneity variance τ^2 [31]. We used Knapp–Hartung adjustments to calculate the confidence interval around the pooled effect. The meta-analyses were performed in R statistical software using the "meta" package with random effects models for both the total weight-loss period and the weight maintenance period, separately [32, 33]. Heterogeneity between effects were analyzed using the I^2 statistic and interpreted as substantial when $> 50\%$ [34]. Publication bias was assessed by visually inspecting funnel plots and Egger's regression test. Any publication bias was investigated by removing outliers and the robustness of this correction was checked by performing a Duval and Tweedie adjustment [35, 36]. Risk of bias analysis including classification of low risk, some concerns, and high risk was analyzed using the Risk of Bias tool Version 2 guidelines [29].

3.3 | Meta-Regression

In a meta-regression, we investigated the unique intervention capacity (i.e., number of BCTs used in the intervention that were not also used in the control condition), intervention focus (i.e., weight loss intervention, weight maintenance intervention, or combined) and study duration. Previously, it has been shown that intervention effectiveness is dependent on the content of comparison intervention or standard care [37]. In other words, comparison interventions generally also consist of active ingredients and hence, the unique added contribution of an experimental intervention may be more limited, when also considering the content of the comparison intervention. Accordingly, the unique intervention capacity was computed as the number of BCTs used in the intervention that were not used in the control group and therefore describes the uniquely added value of each BCT to an effect.

3.4 | BCT Subgroup Analyses

For each BCT, study effects were categorized into the following three groups: (1) BCT was not used in the intervention and not in the control group; (2) BCT was used in the intervention, but not in the control group; and (3) both intervention and control used the BCT. Studies where the control group used the BCT, but the intervention did not, were excluded for the subgroup analyses. Each BCT was examined testing for subgroup differences using a mixed effects model with random effect for the within-subgroup effect sizes and a fixed effects model for testing the between-subgroups heterogeneity [38]. BCTs that showed a between group effect with a $p < 0.10$ with at least three studies in each subgroup were reported. BCTs were considered as effective intervention component when the BCT demonstrated greater effectiveness when used in the intervention but not in the control group compared to when the BCT was absent in both groups. When both intervention and control groups included the BCT and no effect (i.e., difference between intervention and control) was observed, this was interpreted as the effect being masked by equal exposure, suggesting that the BCT may still have a positive influence.

3.5 | Percent Effectiveness Ratio

Additionally, for each BCT, we determined the percentage effectiveness ratio as used in previous reviews [39, 40]. This ratio is computed as the number of times a BCT is used in an effective intervention (i.e., with a significant effect size) compared to the number of times a BCT is used overall. When this percentage effectiveness ratio was larger than 50%, the BCT is considered an effective component of the intervention. This measure was included because it provides an intuitive indicator of how consistent a BCT appears in successful interventions, complementing effect size estimates and helping identify components with practical relevance.

For the subgroup analyses and the percentage effectiveness ratio, we only analyzed the BCTs that were used in at least three interventions.

4 | Results

4.1 | Studies Included and Description of Interventions

Sixty-five studies met the eligibility criteria and were included in the meta-analysis (see Figure 1). Fifty-seven studies targeted both physical activity and a healthy diet. Five studies targeted healthy diet, two targeted physical activity, and one was not specified in that participants solely received a deposit contract without any stimulation and/or support to target either their diet or physical activity behavior [41]. Most of the studies were carried out in the United States of America ($n = 39$). The remaining studies were executed in Australia ($n = 7$), the United Kingdom ($n = 6$), Finland ($n = 3$), Japan ($n = 2$), Latvia ($n = 1$), Singapore ($n = 1$), Kuwait ($n = 1$), Canada ($n = 1$), and two studies collected

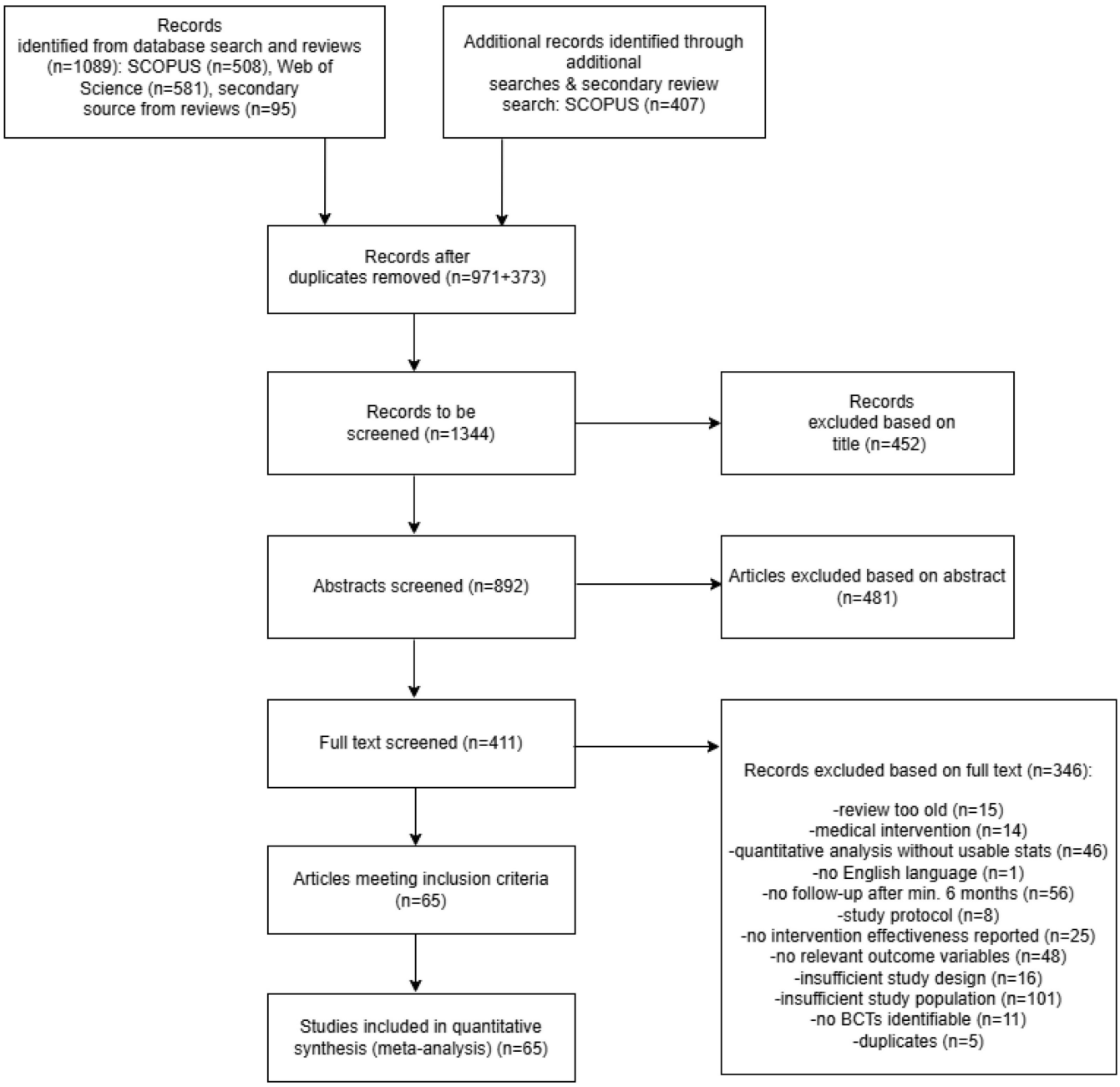

FIGURE 1 | Flowchart of screened articles.

data in multiple countries in Europe (i.e., UK, Netherlands, Norway, Denmark, and Portugal).

Several of these studies evaluated more than one intervention. In total, 87 interventions were analyzed and compared against 67 control groups, as some studies compared multiple interventions to a single control group. Across these interventions, 78 posttreatment effects (short-term; baseline to posttreatment), 52 maintenance effects (posttreatment to follow-up), and 53 long-term effects (baseline to follow-up) were reported. Intervention duration ranged between 3 and 24 months and follow-up time ranged between 6 and 48 months after the posttreatment measurement. Twenty-four interventions were face-to-face, 24 online, and 16 used a combination of both. Eighteen interventions were specifically focused on weight-loss maintenance, and 51 only focused on weight loss. Nineteen interventions were aimed at both weight loss and weight-loss maintenance. Intervention settings varied from university settings, community centers, health or research centers to work sites and military installations. Delivery of the intervention was executed by individuals with different backgrounds such as (trained) wellness coaches, dieticians, psychologists, health coaches, or trained, unspecified intervention or worksite staff. While most of the interventions compared a clearly defined intervention group with either care as usual ($n = 27$) or waiting list control ($n = 10$), a considerable number of interventions employed either a minimal intervention ($n = 19$) or comparable "active intervention" control group ($n = 11$). Most of the interventions asked participants to set health-related goals such as a calorie deficit or a certain amount of moderate physical activity per day. Furthermore, participants often received devices to support self-monitoring such as a pedometer, smart watches, weighing scale, or a calorie tracking logbook. While in several cases participants received encouragement and feedback regarding their health behavior, there were interventions where groups would engage in health meal preparation and/or physical activity classes together. A comprehensive overview of studies and interventions can be found in Appendices 2 and 3, respectively.

4.2 | Description of Effects per Study Arm

Figure 2 presents an overview of the SMD expressed as the Hedges' g grouped by intervention or control; these are study arm effects. For each study-arm effect, the posttreatment effect is marked with a triangle, and the follow-up effects are marked with circles. All interventions are colored blue and the control conditions are colored red. Figure 2 shows that the effects of control conditions are mostly closer to zero, whereas the intervention conditions have larger absolute effects (i.e., more weight loss). Furthermore, the intervention effects seem to decrease over time; posttreatment effects are largest, and effects get closer to zero as follow-up time proceeds.

4.3 | Pooled Between-Group Effects

Figure 3 shows forest plots of the between-group effect sizes for the long-term weight-loss effects (i.e., baseline to last reported follow-up) in the top panel, and the effect sizes for weight maintenance specifically (i.e., posttest to follow-up) in the bottom panel. There are 39 different studies that together reported 53 long-term weight-loss effects, and 41 studies reported on 52 weight maintenance effects. The duration column shows the study duration (in months) and the *N* column the sample size adjusted for multiple group comparisons.

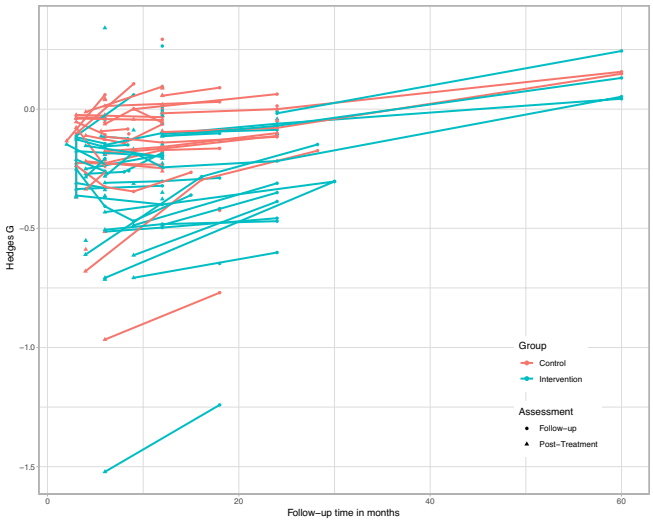

FIGURE 2 | Study arm effects (Hedges' *g*) at posttreatment and follow-up for all control and intervention groups.

The pooled long-term weight-loss effect from the random effects model is −0.19 (95% CI = −0.25 −0.13), interpreted as more weight loss (or less weight gain) in the intervention groups compared with the control groups. The between study heterogeneity variance was $\tau^2 = 0.009$ (95% CI = 0.002–0.068) with an I^2 value of 34.0% (95% CI = 7.4–53.0), which is less than substantial.

For the maintenance period, the posttreatment time-point until the last follow-up, the pooled effect from the random effects model was −0.001 (95% CI = −0.04–0.04) and thus closer to zero and not significant. The between study heterogeneity variance was $\tau^2 < 0.0001$ (95% CI = 0.000–0.001) with an I^2 value of 0% (0.00–32.7).

4.4 | Publication Bias

Publication bias was investigated with a Funnel plot (see Appendix 4) and Egger's regression test of the intercept. These results show that there is an indication for publication bias for the total weight loss effect. To investigate the effect of this possible bias, trimming and filling analyses of Duval and Tweedie were performed. Because we have moderate heterogeneity ($I^2 = 34\%$), we also performed the trimming and filling analysis to the data when two outlier studies were removed: study 33 Morgan (2013) and study 25 Kaikkonen (2019). The results for these analyses are presented in Appendix 5. The pooled effect size seems quite robust over the analyses: the effects remain negative and significant but are a little smaller. The heterogeneity is drastically decreased by removing the two outlier studies but increases in the trim and fill analyses,

which is to be expected [35]. Because the pooled effects do not lead to different conclusions about the pooled results when we include or remove the outliers, we decided to present the results with all effects included in the remainder of the study. Egger's regression and inspection of the Funnel plots showed no indication of publication bias for the weight maintenance effects.

4.5 | Meta-Regression

To evaluate the impact of covariates, we examined the statistical significance and the magnitude of the reduction in the effect size variability. For the total weight-loss period, study duration and unique intervention capacity reduced the variability in effect sizes (I^2) to about half its value, and about a third to half of the differences in true effect sizes (R^2) can be explained by each predictor (Table 2). The intervention focus (i.e., interventions that targeted weight loss, interventions that focused on the period of weight maintenance and interventions that focused on both the period of weight loss and maintenance) explained nearly a third of the variance in the effects, but did not account for any heterogeneity in the effect sizes. However, the presence of remaining heterogeneity indicates that other factors (e.g., BCTs) likely contribute to differences in intervention effectiveness. For the weight maintenance period, there is no heterogeneity in the effect sizes, accordingly, tests for moderators of intervention focus, study duration, and unique intervention capacity were not significant and did not explain any variance in the effects.

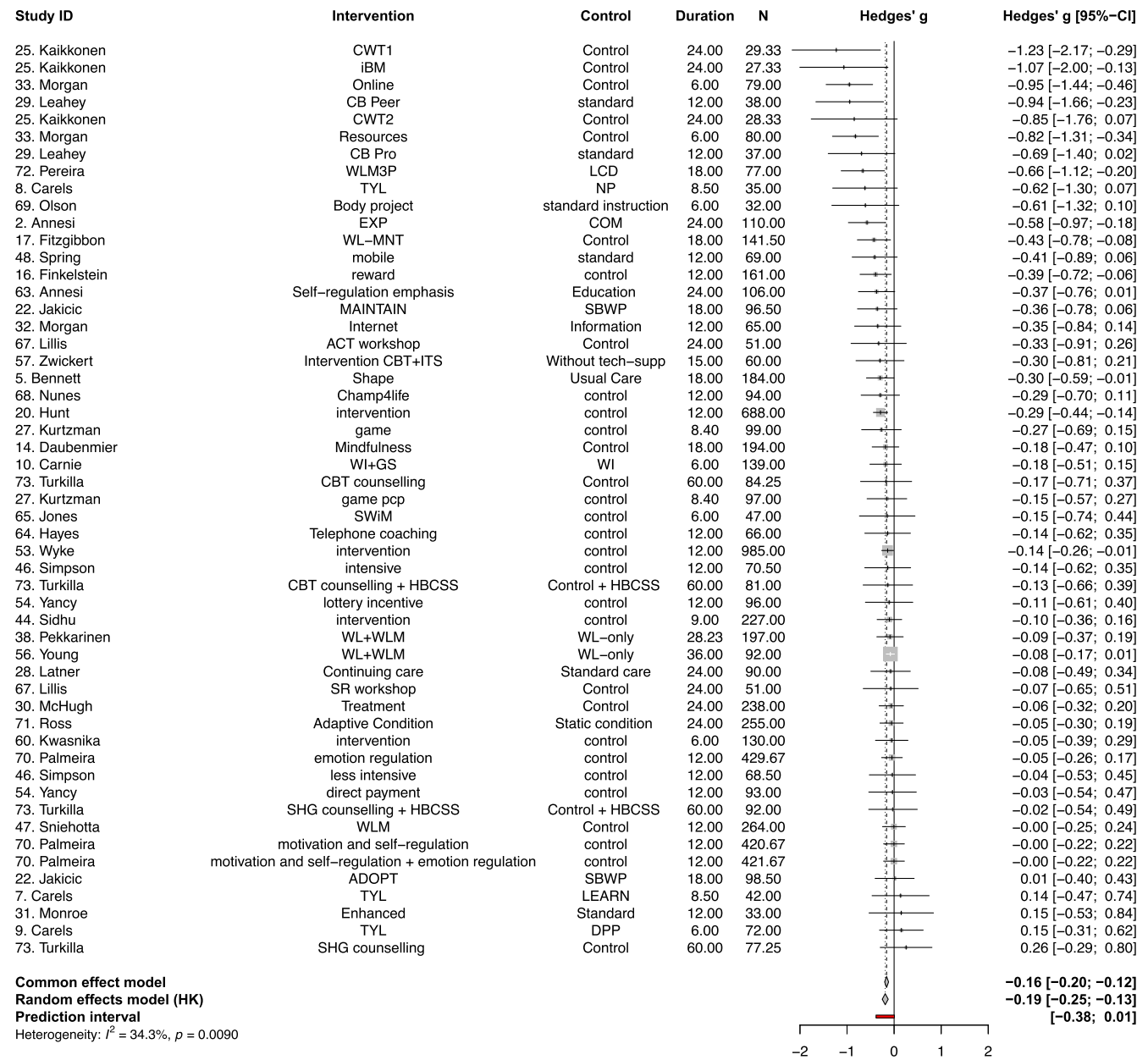

FIGURE 3 | Meta-analysis of long-term weight-loss effects (top panel) and weight maintenance effects (bottom panel). Note that the sample size for the control group was adjusted when multiple comparisons were made within one study.

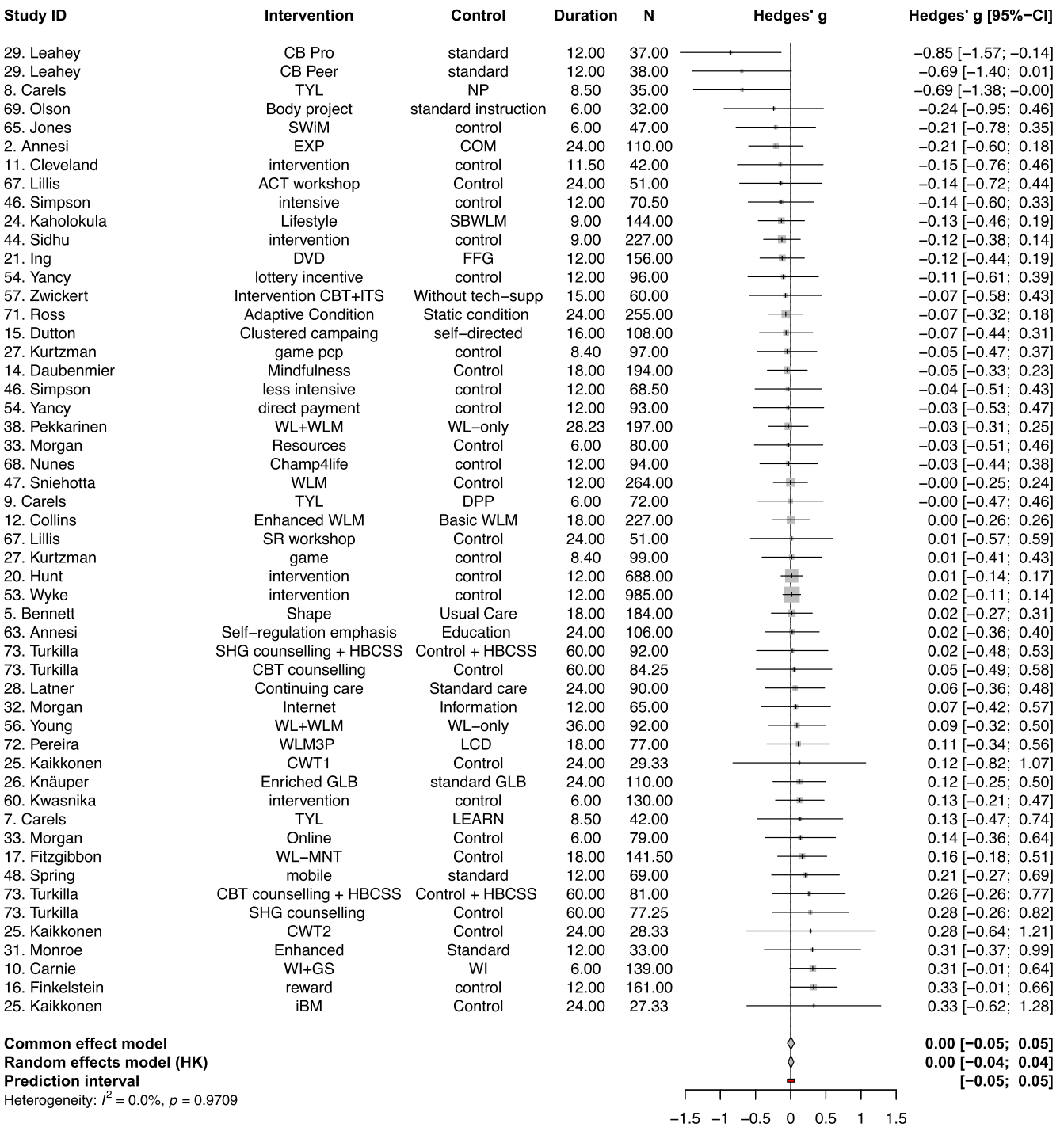

FIGURE 3 | (Continued)

4.6 | BCT Subgroup Analyses

The results of the BCT subgroup analyses for the total weight-loss period are presented in Table 3. Subgroup analyses compared the following three conditions for each BCT: (1) not used in either intervention or control, (2) used in the intervention only, and (3) used in both intervention and control groups. Thirteen BCT subgroup analyses had a between subgroup difference with $p < 0.10$. For BCTs "demonstration of the behaviour" (BCT 6.1) and "conserving mental resources" (BCT 11.3), interventions that included the BCT while controls did not showed the strongest effects compared to the other subgroups, where effects were absent or smaller (a similar pattern was observed for "incentives" (BCT 10.7/10.8), though not statistically significant). For BCTs "feedback on behaviour" (BCT 2.2), "feedback on outcome(s) of behaviour" (BCT 2.7), "self-monitoring of behaviour" (BCT 2.3), "self-monitoring of outcome(s) of behaviour" (BCT 2.4), and "instruction on how to perform the behaviour" (BCT 4.1), effectiveness was observed when the BCT was used in the intervention only or not used at all, but no effect was found when the BCT was applied in both groups, suggesting that equal exposure may mask its influence. For "goal setting" (BCT

TABLE 2 | Meta-regression results for univariate analyses for total weight loss period and maintenance period.

	Total weight loss period				Weight maintenance period			
	Coefficient (95% CI)	τ^2	I^2	R^2	Coefficient (95% CI)	τ^2	I^2	R^2
Intervention focus		0.008	21.24	0.00		0.00	0.00	0
Maintenance vs. weight loss	−0.037(−0.190–0.116)				−0.074(−0.192–0.044)			
Both vs. weight loss	−0.051(−0.209–0.106)				−0.026(−0.166–0.114)			
Unique intervention capacity	−0.011(−0.030–0.007)	0.005	16.26	29.96	0.006(−0.008–0.020)	0.00	0.00	0
Study duration[a]	0.003(−0.002–0.009)	0.005	13.75	39.32	0.005(−0.013–0.023)	0.00	0.00	0

[a]Study duration is baseline until last follow-up for the total weight loss period, and posttreatment until the last follow-up for the weight maintenance period, expressed in months.

1.1/1.3), the strongest effect occurred when used in the intervention only, but a substantial effect was also present when used in both groups, with no effect when absent. Conversely, for BCTs "reducing negative emotions" (BCT 11.2), "framing/reframing" (BCT 13.2), "identity associated with changed behaviour" (BCT 13.5), and "habit formation" (BCT 8.3), interventions without these BCTs showed better outcomes than those that included them, indicating a reversed effect. For the maintenance period, we found between subgroup differences for "goal setting" (BCT 1.1/1.3), "self-monitoring of behavior" (2.2), "incentive" (BCT 10.7/10.8), "material incentive/reward" (BCT 10.1/10.2), and "reducing negative emotions" (BCT 11.2) (Appendix 6). For most of these BCTs, the subgroup effects were not significant, only for "reducing negative emotions" (BCT 11.2); we found a significant combined effect during the maintenance period, when this BCT was used in the intervention and not in the control.

4.7 | Percentage Effectiveness Ratio

Figure 4 shows the percentage effectiveness ratio over the total weight-loss period, for each BCT that occurred in at least three interventions. BCTs are effective when the percentage effectiveness ratio is larger than 50%. The total effect displays the effectiveness when the BCT was used in the intervention, and the unique effect displays the effectiveness when the BCT was used in the intervention and not in the control. "Demonstration of behaviour" (BCT 6.1) and "incentive (outcome)" (BCT 10.7–10.8) are part of effective interventions as well in total as in unique occurrence. For the weight maintenance period, no BCTs have a percentage effectiveness ratio larger than 50% (Appendix 7).

4.8 | Risk of Bias

The overall risk of bias did explain almost half of the heterogeneity between the effects ($R^2 = 40\%$), but the fixed effects for low risk or some concerns did not significantly differ from the high-risk studies. In Appendix 8, the risk of bias is shown in each subcategory. Bias arising from randomization was mostly low, as was the bias of the outcome measurement and selection of reported results. Bias due to deviations from the intended interventions caused some concerns, mostly because studies did not always report information about checking the adequate execution of the intervention. Additionally, high risk of bias due to missing outcome data often resulted from using last observation carried forward as a missing data strategy or completers analyses. Both last observation carried forward and completer analyses are proven to have a high chance to result in unstable or even biased estimates, and its use should be avoided [42].

5 | Discussion

5.1 | Principal Findings

This systematic review and meta-analysis evaluated the effectiveness of behavioral weight-loss interventions on (1) long-term weight outcomes across intervention and follow-up, (2) weight maintenance during the postintervention maintenance phase, and (3) the contribution of BCTs to long-term weight outcomes. Both analyses compared intervention groups to control groups to assess differences in outcomes.

Behavioral weight-loss interventions result in significant effects on weight loss over the total period, which included both the intervention phase and the maintenance phase (i.e., weight loss between baseline and follow-up). The intervention groups lost more weight than control groups (Hedges' $g = 0.19$). Intervention focus (i.e., if the intervention was aimed at weight loss, weight maintenance, or both) did not explain differences in the effects between studies, consistent with earlier research of Dombrowski et al. [10].

When examining the weight maintenance period only (posttreatment to follow-up), no significant difference between the intervention and control group was observed. This suggests that, on average, between-group differences achieved during the intervention phase were maintained over follow-up, with no statistically significant evidence of greater weight regain in the intervention group compared with controls. This is an important finding for understanding the relative longer-term effects of behavioral interventions. However, this finding should also be interpreted in the context of obesity as a condition that is not

TABLE 3 | BCT subgroup analyses for the total weight loss period.

	Subgroups	*k*	Hedges G (95% CI)	Within test *p*	I^2 (95% CI)	Between test *p*
Goal setting (behaviour) (BCT 1.1/BCT1.3)	Not used	14	−0.052 (−0.122–0.018)	0.132	0 (0–0.55)	0.000
	Intervention only	21	−0.301 (−0.423-0.179)	0	0.421 (0.028–0.655)	
	Both groups	16	−0.23 (−0.356-0.103)	0.001	0.35 (0–0.643)	
Problem solving (BCT1.2)	Not used	19	−0.114 (−0.179-0.048)	0.002	0.139 (0–0.495)	0.159
	Intervention only	19	−0.244 (−0.372-0.116)	0.001	0.495 (0.142–0.703)	
	Both groups	10	−0.152 (−0.281-0.023)	0.026	0 (0–0.624)	
Goal setting (outcome) (BCT1.3)	Not used	14	−0.15 (−0.248-0.052)	0.006	0 (0–0.55)	0.365
	Intervention only	25	−0.252 (−0.369-0.135)	0	0.51 (0.224–0.691)	
	Both groups	11	−0.201 (−0.366-0.036)	0.022	0.036 (0–0.617)	
Action planning (BCT1.4)	Not used	31	−0.224 (−0.327-0.12)	0	0.431 (0.127–0.629)	0.455
	Intervention only	18	−0.149 (−0.244-0.053)	0.004	0.252 (0–0.577)	
	Both groups	4	−0.237 (−0.504–0.03)	0.067	0 (0–0.847)	
Review behaviour goal(s) (BCT1.5)	Not used	40	−0.2 (−0.293-0.108)	0	0.42 (0.153–0.602)	0.992
	Intervention only	10	−0.197 (−0.264-0.131)	0	0 (0–0.624)	
	Both groups	3	−0.217 (−0.934–0.5)	0.322	0.609 (0–0.889)	
Review outcome goal(s) (BCT1.7)	Not used	48	−0.196 (−0.269-0.123)	0	0.394 (0.141–0.573)	0.315
	Intervention only	5	−0.148 (−0.238-0.058)	0.01	0 (0–0.792)	
Commitment (BCT1.9)	Not used	50	−0.191 (−0.259-0.123)	0	0.379 (0.124–0.56)	0.099
	Intervention only	3	−0.129 (−0.201-0.057)	0.016	0 (0–0.896)	
Feedback on behaviour (BCT2.2)	Not used	27	−0.256 (−0.365-0.147)	0	0.423 (0.088–0.635)	0.015
	Intervention only	10	−0.237 (−0.399-0.075)	0.009	0.435 (0–0.729)	
	Both groups	15	−0.077 (−0.167–0.012)	0.084	0 (0–0.536)	
Self-monitoring of behaviour (BCT2.3)	Not used	8	−0.197 (−0.428–0.033)	0.082	0.215 (0–0.636)	0.071
	Intervention only	20	−0.259 (−0.382-0.136)	0	0.451 (0.072–0.676)	
	Both groups	23	−0.109 (−0.176-0.042)	0.003	0.193 (0–0.514)	

(Continues)

TABLE 3 | (Continued)

	Subgroups	*k*	Hedges G (95% CI)	Within test *p*	I^2 (95% CI)	Between test *p*
Self-monitoring of outcome(s) of behaviour (BCT2.4)	Not used	27	−0.2 (−0.273-0.127)	0	0.132 (0–0.454)	0.003
	Intervention only	9	−0.402 (−0.661-0.143)	0.007	0.663 (0.318–0.834)	
	Both groups	16	−0.087 (−0.151-0.023)	0.011	0 (0–0.523)	
Feedback on outcome(s) of behaviour (BCT2.7)	Not used	37	−0.253 (−0.345-0.161)	0	0.444 (0.178–0.623)	0.001
	Intervention only	5	−0.181 (−0.447–0.086)	0.133	0.369 (0–0.765)	
	Both groups	10	−0.059 (−0.114-0.004)	0.039	0 (0–0.624)	
Social support (BCT3.1)	Not used	36	−0.209 (−0.288-0.131)	0	0.327 (0–0.553)	0.240
	Intervention only	11	−0.115 (−0.247–0.017)	0.081	0.225 (0–0.613)	
	Both groups	5	−0.346 (−0.776–0.083)	0.089	0.288 (0–0.723)	
Instruction on how to perform the behaviour (BCT4.1)	Not used	32	−0.139 (−0.213-0.066)	0.001	0.344 (0–0.574)	0.037
	Intervention only	13	−0.219 (−0.366-0.071)	0.007	0.465 (0–0.719)	
	Both groups	7	−0.331 (−0.495-0.167)	0.003	0 (0–0.708)	
Information about antecedents (BCT4.2)	Not used	48	−0.204 (−0.274-0.135)	0	0.364 (0.095–0.553)	0.073
	Intervention only	4	−0.059 (−0.293–0.176)	0.484	0 (0–0.847)	
Information about health consequences (BCT5.1)	Not used	50	−0.19 (−0.259-0.122)	0	0.366 (0.104–0.551)	0.548
	Intervention only	3	−0.151 (−0.392–0.09)	0.114	0 (0–0.896)	
Demonstration of the behaviour (BCT6.1)	Not used	44	−0.154 (−0.213-0.095)	0	0.164 (0–0.429)	0.053
	Intervention only	5	−0.466 (−0.908-0.025)	0.043	0.632 (0.029–0.861)	
Prompts/Cues (BCT7.1)	Not used	45	−0.175 (−0.245-0.105)	0	0.349 (0.061–0.548)	0.111
	Intervention only	5	−0.285 (−0.509-0.06)	0.025	0.223 (0–0.677)	
	Both groups	3	−0.054 (−0.379–0.271)	0.551	0 (0–0.896)	
Remove aversive stimulus (BCT7.5)	Not used	50	−0.174 (−0.236-0.111)	0	0.324 (0.04–0.524)	0.412
	Intervention only	3	−0.333 (−1.16–0.493)	0.225	0.467 (0–0.843)	
Behavioural practice/rehearsal (BCT8.1)	Not used	41	−0.16 (−0.223-0.097)	0	0.275 (0–0.509)	0.595
	Intervention only	7	−0.24 (−0.601–0.121)	0.154	0.519 (0–0.795)	

(Continues)

TABLE 3 | (Continued)

	Subgroups	*k*	Hedges G (95% CI)	Within test *p*	I^2 (95% CI)	Between test *p*
Habit formation (BCT8.3)	Not used	48	−0.207 (−0.276-0.138)	0	0.379 (0.117–0.563)	0.003
	Intervention only	4	0.013 (−0.196–0.223)	0.854	0 (0–0.847)	
Graded tasks (BCT8.7)	Not used	43	−0.185 (−0.255-0.115)	0	0.356 (0.064–0.557)	0.298
	Intervention only	7	−0.349 (−0.725–0.027)	0.063	0.51 (0–0.792)	
Nonspecific reward (BCT10.3)	Not used	50	−0.192 (−0.257-0.127)	0	0.344 (0.071–0.537)	0.435
	Intervention only	3	−0.064 (−0.756–0.628)	0.729	0.365 (0–0.798)	
Incentives (BCT10.7/10.8)	Not used	44	−0.164 (−0.221-0.106)	0	0.132 (0–0.405)	0.099
	Intervention only	5	−0.46 (−0.96–0.04)	0.063	0.628 (0.015–0.859)	
Material reward/incentive (BCT10.1/10.2)	Not used	48	−0.173 (−0.236-0.109)	0	0.327 (0.038–0.529)	0.574
	Intervention only	3	−0.24 (−0.736–0.257)	0.173	0 (0–0.896)	
Reducing negative emotions (BCT11.2)	Not used	42	−0.232 (−0.312-0.151)	0	0.427 (0.172–0.604)	0.001
	Intervention only	6	−0.041 (−0.125–0.043)	0.266	0 (0–0.746)	
	Both groups	3	−0.148 (−0.327–0.031)	0.071	0 (0–0.896)	
Conserving mental resources (BCT11.3)	Not used	45	−0.173 (−0.239-0.106)	0	0.264 (0–0.493)	0.037
	Intervention only	5	−0.453 (−0.815-0.091)	0.025	0.461 (0–0.802)	
Restructuring the physical environment (BCT12.1)	Not used	49	−0.191 (−0.256-0.126)	0	0.356 (0.086–0.546)	0.451
	Intervention only	4	−0.062 (−0.595–0.47)	0.734	0.223 (0–0.881)	
Adding objects to the environment (BCT12.5)	Not used	49	−0.174 (−0.231-0.116)	0	0.174 (0–0.425)	0.277
	Intervention only	4	−0.433 (−1.187–0.321)	0.165	0.849 (0.625–0.939)	
Framing/reframing (BCT13.2)	Not used	43	−0.21 (−0.292-0.129)	0	0.423 (0.17–0.6)	0.021
	Intervention only	8	−0.101 (−0.159-0.044)	0.004	0 (0–0.676)	
Identity associated with changed behaviour (BCT13.5)	Not used	46	−0.206 (−0.28-0.133)	0	0.389 (0.126–0.572)	0.025
	Intervention only	5	−0.078 (−0.201–0.046)	0.155	0 (0–0.792)	

Abbreviations: CI = confidence interval, I^2 = between study heterogeneity, *k* = number of studies in the subgroup.

FIGURE 4 | Percentage effectiveness ratio over the total weight-loss period for each BCT. The red lines show the total effect of the BCT and the blue lines the unique effect for the BCT.

only shaped by biological and behavioral factors, but also is challenged by persistent obesogenic environments. Accordingly, interventions targeting individual behavior change should be complemented by interventions addressing the obesogenic environment [43].

5.2 | BCT Effectiveness

Subgroup analyses revealed notable differences in the effectiveness of specific BCTs across intervention conditions. For the total weight-loss period, "goal setting" (BCT 1.1/1.3) emerged as one of the most robust techniques, showing the strongest effect when applied in the intervention only, and still a substantial effect when used in both intervention and control groups. This finding aligns with previous research identifying goal setting as a key strategy for promoting healthy nutrition and physical activity behaviors [21, 39, 44]. Similarly, BCTs such as "feedback on behaviour"(BCT 2.2) and "feedback on outcome(s) of behaviour" (BCT 2.7), as well as "self-monitoring of behaviour" (BCT 2.3) and "self-monitoring of outcome(s) of behaviour" (BCT 2.4), were effective when applied exclusively in intervention groups or not at all, but showed no effect when used in both groups, suggesting that equal exposure may attenuate or mask their influence. These results are consistent with evidence from other health domains, where self-monitoring and feedback have been shown to improve dietary and physical activity behaviors [21, 39]. However, our findings extend this evidence by demonstrating their relevance for weight outcomes, rather than behavioral proxies alone.

"Demonstration of behaviour" (BCT 6.1) and "conserving mental resources" (BCT 11.3) were associated with the strongest effects when used in interventions and not in controls, highlighting the potential value of practical and cognitive support strategies in weight-loss programs. Interestingly, "incentives" (BCT 10.7–10.8) showed a positive trend, though not statistically significant, suggesting that motivational components may support engagement within behavioral interventions. Conversely, BCTs such as "reducing negative emotions" (BCT 11.2), "framing/reframing" (BCT 13.2), "identity associated with changed behaviour" (BCT 13.5), and "habit formation" (BCT 8.3) were linked to weaker or reversed effects, indicating that these strategies may require more targeted application or longer intervention periods to demonstrate benefit.

During the maintenance period, the absence of a significant difference between intervention and control groups indicates relative stability of between-group differences over follow-up, without statistically significant evidence of differential weight regain. This stability suggests that the initial advantage of the intervention remained intact throughout follow-up. Given the low heterogeneity across studies, we did not expect subgroup analyses to reveal strong moderators. Against this backdrop, the finding that interventions including "reducing negative emotions" (BCT 11.2) achieved greater weight loss during the maintenance period is noteworthy, particularly because this BCT showed a reversed effect when considering the total weight-loss period. This phase-specific effect may reflect changing demands of behavior regulation: Early weight loss relies on action-oriented strategies such as goal setting, feedback, and self-monitoring regarding dietary control and physical activity, whereas long-term maintenance requires coping with stress, emotional triggers, and societal pressures. By fostering mindfulness, awareness of hunger cues, and adaptive coping, emotion-focused interventions may enhance resilience and prevent relapse. These findings may underscore the importance of sequencing BCTs, integrating emotional regulation components more prominently toward the maintenance phase. Such strategies may help individuals manage the challenges of weight regain over time.

Taken together, these findings suggest that volitional and self-regulation strategies, especially goal setting, feedback, self-monitoring, and behavioral instruction, remain central to supportive components of effective weight-loss interventions. While these BCTs have previously been linked to improvements in dietary and physical activity behaviors, our results indicate that they also contribute to clinically relevant weight outcomes. Future research should explore how these techniques interact when combined and whether their effectiveness can be enhanced through tailored delivery formats or integration with motivational components such as incentives.

We did not find an effect for the unique intervention capacity. This measure defines the number of BCTs used in the intervention that are not presented to the control group. This is not in line with earlier research [21, 44–46], which found that the total number of BCTs was associated with larger effects. A possible explanation would be that control groups were active controls in these studies and not considered as such.

5.3 | Strengths

Strengths include a systematic approach, updated searches, and use of a validated BCT taxonomy for coding intervention components. Only RCTs were included, and both intervention and control groups were coded to avoid underestimating effects.

Analyses focused on BCTs present in at least three studies, reducing the likelihood of spurious findings. The inclusion of percentage effectiveness ratios further supports robust identification of effective BCTs [18]. This review is unique in focusing on weight as the outcome and on long-term maintenance effects, addressing gaps in previous research that examined short-term effects or behavioral proxies [10, 21, 44].

5.4 | Limitations and Recommendations

Several limitations should be noted. Fidelity of the intervention delivery was often underreported, and coding BCTs can be challenging due to insufficient detail or discrepancies in descriptions [21]. We could not analyze BCTs absent from all interventions or those included in fewer than three studies. Future research should examine these techniques, as some (e.g., social rewards or incentives, or behavioral substitution) relate to key elements of behavioral maintenance [15]. Additionally, percentage effectiveness ratios may, due to its dichotomous categorization, skew the precision of indicating effective BCTs in case of "smaller," yet more frequently coded BCTs adding to the overall effect [47]. In addition, we need to acknowledge that behavioral interventions are complex, not only comprising multiple BCTs, but also differing in terms of delivery [48, 49]. Variability in delivery mode may also influence effectiveness; prior work suggests dynamically tailored interventions combining automated and human feedback are most effective [50]. Finally, analyses were observational and limited to individual BCTs. We were unable to examine interactions or combinations of BCTs because of the low frequency of certain BCT's occurring together across studies. This is an important constraint, as BCTs are rarely implemented in isolation in real-world interventions; their effectiveness may depend on synergistic or additive effects when combined. Although follow-up durations in the included studies ranged from 6 to 48 months posttreatment, this timeframe may be insufficient to fully capture longer-term weight trajectories characteristic of obesity as a chronic condition, where weight regain may occur over several years. Future research should therefore explore these interactions using designs or datasets that allow for multivariable modeling or network meta-analysis. Moreover, longer follow-up periods ($\geq$ 12 months) are needed to assess sustained effects [51].

5.5 | Conclusions

Behavioral weight-loss interventions result in significant long-term weight difference relative to control conditions, and weight reductions achieved during the intervention phase are generally maintained as between-group differences over follow-up, without statistically significant evidence of differential weight regain. Interventions incorporating goal setting, feedback on behavior and outcome(s) of behavior, self-monitoring of behavior and outcome(s) of behavior, instructions on how to perform the behavior, demonstrations of the behavior, conserving mental resources, and outcome incentives appear most effective. These findings provide actionable insights for designing interventions that support both initial weight loss and longer-term weight outcomes within the context of obesity as a chronic, relapsing condition.

Conflicts of Interest

The authors declare no conflicts of interest.

Data Availability Statement

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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Supporting Information

Additional supporting information can be found online in the Supporting Information section. **Data S1:** Supporting Information.