Received: 30 April 2019 | Revised: 2 July 2019 | Accepted: 2 July 2019
DOI: 10.1111/obr.12916

BEHAVIOR/OBESITY TREATMENT

WILEY obesityreviews

Cognitive training on eating behaviour and weight loss: A meta-analysis and systematic review

Yingkai Yang[1] | Grant S. Shields[2] | Qian Wu[1] | Yanling Liu[1] | Hong Chen[1,3] | Cheng Guo[1]

[1] The Lab of Mental Health and Social Adaptation, Faculty of Psychology, Research Center of Mental Health Education, Southwest University, Chongqing, China

[2] Department of Psychology, University of California, Davis, California, USA

[3] Key Laboratory of Cognition and Personality (Ministry of Education), Southwest University, Chongqing, China

Correspondence
Cheng Guo and Yingkai Yang, Faculty of Psychology, Southwest University, No. 2 Tiansheng Street, Beibei District, 400715 Chongqing, China.
Email: guochen@swu.edu.cn; yykjiyisuipian@gmail.com

Hong Chen, Key Laboratory of Cognition and Personality (Ministry of Education), Southwest University, No. 2 Tiansheng Street, Beibei District, 400715 Chongqing, China.
Email: chenhg@swu.edu.cn

Funding information
Fundamental Research Funds for the Central Universities, Grant/Award Number: SWU1909106

Summary

Cognitive deficits play a role in the development and maintenance of overeating and obesity, and cognitive training in obesity refers to a family of interventions aimed at reducing overeating and obesity by improving these cognitive deficits. In this review, we synthesize the current literature on these issues by conducting a meta-analysis of studies investigating the effects of cognitive trainings on eating behaviour and presenting a systematic review of studies investigating the effects of cognitive trainings on weight loss. We examined 66 independent experiments that examined the effects of cognitive training aimed at reducing cognitive bias or improving executive control on eating behaviour and weight loss. Overall, inhibition training, attention bias modification training, and episodic future thinking training significantly influenced eating behaviour; however, approach/avoidance training did not significantly influence eating behaviour. Moderator analyses indicated that the effect of inhibition training on eating behaviour was moderated by training task and food novelty, the effect of approach/avoidance training was moderated by food type, and the effect of episodic future thinking training was moderated by type of episodic future thinking. Literature reviewed on cognitive training and weight loss provided preliminary support for the effects of food-specific inhibition training on weight loss from pre-intervention to post intervention. However, because most of the included studies focused on short-term outcomes in normal-weight samples, longer duration studies in clinical populations (eg, individuals with obesity) are needed to examine the generalizability of these results.

KEYWORDS

cognitive training, eating behaviour, meta-analysis, weight loss

1 | INTRODUCTION

Excess weight has become a cause of growing health care costs and accounts for over 2.8 million deaths per year,[1] emphasizing the need for effective treatment. In order to promote weight loss, interventions such as behavioural interventions or bariatric surgery are frequently implemented. However, the amount of weight loss achieved via behavioural weight loss interventions is, at best, only modest and rarely does it last.[2] Although bariatric surgery is an effective weight loss intervention for severe obesity, it is highly invasive and can result in medical complications.[3] Therefore, it is vital to identify novel, non-invasive interventions that foster weight loss.

Recent literature emphasizes the importance of cognitive mechanisms in the regulation of eating behaviour and body weight.[4-7] Many people nowadays live in an obesogenic food environment and are constantly exposed to appetitive yet unhealthy foods, especially those that contain much sugar and fat.[8] In such an environment, unhealthy eating behaviour (eg, forgoing healthy foods in favour of inexpensive, high-calorie, unhealthy foods) become a key contributor to the increasing rates of overweight and obesity,[1] begging the question, how can we foster healthier eating behaviour?

1.1 | Role of cognitive deficits in the development and maintenance of overeating and obesity

Cognitive deficits may put individuals at risk for unhealthy eating behaviour.[9-14] Therefore, it is plausible that cognitive trainings aimed to ameliorate cognitive deficits have beneficial effects on eating behaviour or body weight.[5-7] Two classes of cognitive deficits are commonly examined by obesity researchers: cognitive biases and executive control deficits. A cognitive bias here refers to the selective processing (eg, attending to or approaching) of relevant information over other information in the environment.[15] Executive control, on the other hand, refers to the higher cognitive processes that enable forethought and goal-directed action.[16,17] In the case of obesity, studies have found that cognitive bias (eg, a strong automatic approach to or attentional capture by high-calorie food cues), or low levels of executive control were related to obesity-related eating behaviours and outcomes (eg, increased intake of fatty foods, weight gain).[4,18,19] Note that few studies (but see Kakoschke et al[9]) have directly examined potential interactions between cognitive biases and executive control.

In addition, compared with persons with normal weight, individuals with obesity show a more positive association with food and cognitive biases—including an attentional bias (eg, greater proportional allocation of attention to appetitive cues)[20] and an approach bias (eg, an automatic tendency to move towards appetitive cues)—to unhealthy food or typically high-calorie food,[21] although attention bias in obesity is still with controversy.[22] Further, persons with obesity also have significant executive control deficits relative to persons with normal weight.[23] In support of this, meta-analyses[24,25] have found that obesity or greater body mass index (BMI) is associated with relative impairments in executive functions, including poor inhibition, working memory, and cognitive flexibility.

Taken together, overeating (or eventually weight gain) could result from a strong automatic attentional or approach response to high-calorie food and food cues, or from weak executive control.[4,9,18,19] This implies that cognitive training interventions that reduce the cognitive bias to high-calorie food cues or strengthen executive control to such stimuli should decrease overeating that is rooted in exposure to obesogenic food environment, and effectively treat obesity.[5]

1.2 | Cognitive training interventions in overeating and obesity

Five main cognitive training interventions are typically used in overeating and obesity to target cognitive biases or executive control (eg, working memory, inhibition, and delay discounting) including working memory training, inhibition training, attention bias modification training, approach/avoidance training, and episodic future thinking training.

1.2.1 | Working memory training

Working memory training usually utilizes progressively difficult mental exercises (eg, a visuospatial working memory task) to strengthen executive control.[26] For example, during working memory training using the backward digit span task, participants reproduce a sequence of numbers presented on the computer screen in a reversed order, and critically in the active training group, the difficulty level of the task is automatically adjusted on a trial-by-trial basis.

1.2.2 | Inhibition training

Inhibition training (in the context of obesity) includes two types of training: general inhibition training and food-specific inhibition training.[7] The aim of general inhibition training is to increase overall inhibitory control through training to often arbitrary cues.[7] Food-specific inhibition training, in contrast, pairs specific food cues with "no-go" or "stop" signals to promote associative links between food cues and engagement of inhibitory control.[27] For example, during food-specific inhibition training using a food go/no-go task, participants need to quickly response (eg, press space bar) to the food picture (eg, high- and low-calorie food pictures) displayed on the computer screen and to withhold this response when a stop signal (eg, the frame around the picture turns bold) is displayed. Critically, to establish the inhibition association with unhealthy food, in the active training group, the stop signals are disproportionately paired with high-calorie food pictures (eg, 90%). By contrast, in the control group, stop and go signals are usually equally (eg, 50%) paired with the food cues.

One important moderator of inhibition training effects on eating behaviour may be the inhibition training task. That is, the go/no-go task has a much higher cue-inhibition contingency than the stop signal task used in inhibition training (see Table S1), which may lead to a more robust association between inhibitory control and no-go food, possibly resulting in a superior effectiveness of the go/no-go task.[28]

Another potential important moderator of inhibition training effects on eating behaviour may be food novelty in the outcome measure. Indeed, compared with its effect on generalized food (eg, new food), some evidence suggests that the effect of inhibition training on eating behaviour is relatively larger when the outcome measure of eating behaviour used the same food as the food cues used in the training task.[29]

1.2.3 | Attention bias modification training

Attention bias modification training (in the context of obesity) works by training attention away from the appetitive food cues and towards control alternatives.[30] For example, in the active training using modified dot probe task, the control food cue is almost always replaced (eg, 90%) by a probe to which the participant must respond, so that participants should learn an association between the control food cue (healthy food picture or neutral picture) and the likely location of probe, and in turn, learn to direct their attention away from high-calorie food cues. By contrast, in an active control condition, the probe appears with equal frequency in the position of high-calorie food cues and control food cues.

One potential moderator of attention bias modification training effects on eating behaviour may be food novelty. That is, compared with its general effect on food, the effect of attention bias modification training on eating behaviour may be relatively larger when the eating behaviour outcome uses the same food as the food cues used in the training task.[30]

1.2.4 | Approach/avoidance training

Approach/avoidance training aims to retrain any automatic approach responses towards high-calorie food cues by pairing these food cues with an avoidance motor action (ie, pushing a joystick). To do this, in the active training group, participants are instructed to almost always respond (eg, 90%) to pictures of high-calorie food cues by making an avoidance movement (eg, push) and almost always respond (eg, 90%) to pictures of control cues (eg, healthy food picture) making an approach movement (eg, pull). By contrast, in the control group, participants usually equally (eg, 50%) respond to food cues making an approach/avoidance movement.

One potential important moderator of approach/avoidance training effects on eating behaviour may be the food type (eg, unhealthy vs healthy) used in the outcome measure. Some of the studies using approach/avoidance training not only require the avoidance of unhealthy food (eg, high-calorie food) but also require participants to approach-healthy food (eg, fruit and vegetables). This approach-healthy cue movement may change the value of healthy food cues,[31] and in turn make participants choose healthy food rather than unhealthy food when these two types of foods provided on the outcome measure. In contrast, evidence of approach/avoidance training on unhealthy food eating is relatively weak.[32]

1.2.5 | Episodic future thinking training

Episodic future thinking refers to the capacity to project one's self forward in time and simulate experiences that might occur in one's future.[33] This episodic simulation may reduce perceived distance between the future and now, lengthen one's temporal window, and give people the ability to further consider the value of delayed rewards in decision making.[34] In the context of obesity, participants allocated to the episodic future thinking training condition are required to list positive personal events that realistically could happen in the future, the events could be food-related (eg, having dinner with friends), goal-related (eg, going to the gym three times a week), or general future events (eg, celebrating birthday). By contrast, in the active control condition, participants are required to list recently experienced events. In addition, to facilitate a vivid representation of the events, participants are often required to consider as many details of this event as possible (eg, contextual who, when, what, where).

According to the events that participants are asked to generate, episodic future thinking can be divided into food-related, goal-related, or general episodic future thinking. The type of episodic future thinking could be an important moderator of the effects of episodic future thinking on eating behaviour, since some evidence suggests that the effect of episodic future thinking training may be most apparent when participants generate food-related events.[34]

1.3 | Present research

Several reviews have been conducted to summarize empirical findings regarding the effects of cognitive training in eating behaviour and obesity.[6,7,35-37] These reviews, together with the fact that this field is growing rapidly, inspired the current study, which conducted a meta-analysis to evaluate if cognitive training interventions are effective in changing eating behaviour as well as an updated systematic review to evaluate if cognitive training interventions could lead to weight loss.* Specifically, this paper focuses on cognitive trainings focused on cognitive bias or executive control that have been tested in human participants. According to this criteria, we conducted this meta-analysis and systematic review for five cognitive training interventions: working memory training, inhibition training, attention bias modification training, approach/avoidance training, and episodic future thinking training.

2 | METHOD

2.1 | Study selection and inclusion criteria

2.1.1 | Literature review

To obtain studies for use in the meta-analysis, a topic search in the databases PubMed, ISI Web of Knowledge, and PsycINFO was conducted for all papers published until 17 January 2019 (see Appendix S1 for a list of keywords).

In this search, PubMed returned 4195 results, PsycINFO returned 1238 results, and Web of Science returned 2337 results. Abstracts of articles were reviewed, and the full text of an article was read whenever a paper's title or abstract indicated that the study might be relevant to analyses. In addition, to help ensure that all studies on this topic were included, references from relevant articles were reviewed, and studies that were potentially relevant were examined from those references. Figure 1 outlines the detailed study selection procedure.

2.1.2 | Inclusion criteria.

Studies were incorporated into this research if they (a) examined human participants with normal weight or excessive weight (eg, overweight or obesity), (b) administered at least one of the five cognitive training interventions described above, (c) used at least one control

*Originally, we also intended to conduct a meta-analysis on the weight loss effect of cognitive training. However, only 13 studies meet the inclusion criteria after the literature search (for more, see Section 3.1.1.), this lead to average two studies on each cognitive intervention. In addition, most of the studies did not report enough information to calculate effect sizes. Based on this, we present an updated systematic review rather than a meta-analysis on weight loss.

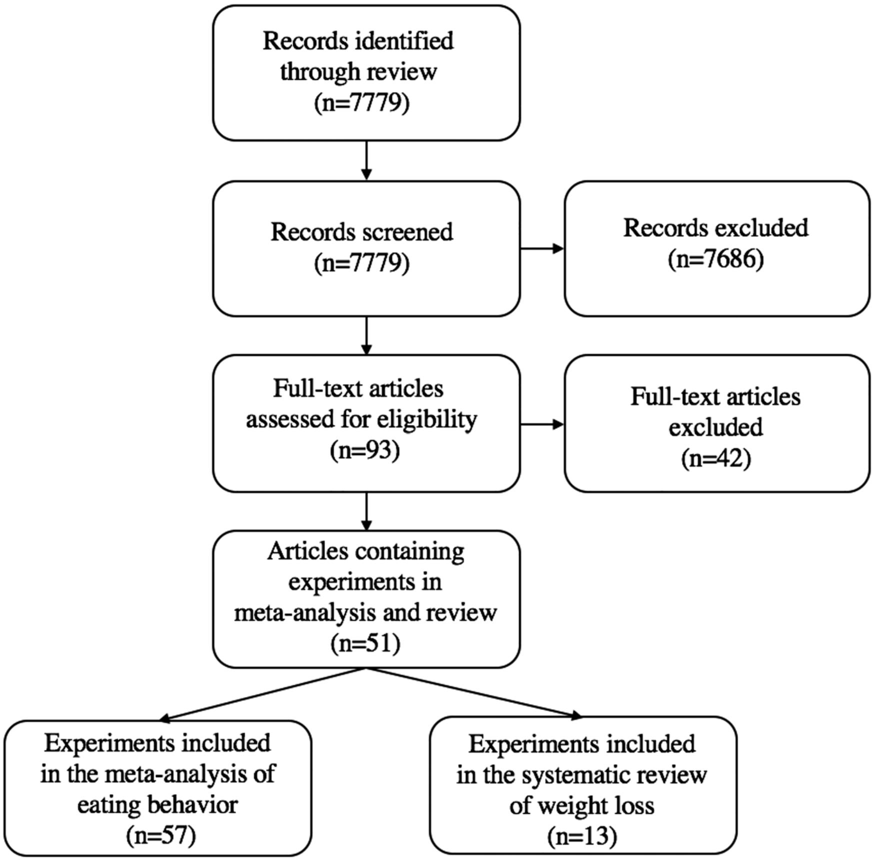

FIGURE 1 Flow diagram illustrating the process of our review, screening, and article selections

group/condition, and (d) included an outcome measure related to eating behaviour or weight—for example, a bogus taste test, food choice in a free choice situation, food diary or questionnaire data, or BMI or body fat. In addition, if studies included an outcome measure related to eating behaviour, it must have provided sufficient data or statistical information to calculate an effect size to be included in our analyses.

2.2 | Coding of variables

Interventions using visuospatial working memory tasks, the backward digit span task, the letter span task, or tasks taping into maintenance and updating abilities were coded as working memory training. Interventions using the go/no-go task or stop signal task were coded as inhibition training. Interventions using modified dot probe task, modified antisaccade task, or modified Stroop task were coded as attention bias modification training. Interventions using approach/avoidance tasks were coded as approach/avoidance training. Finally, interventions facilitating episodic future thinking were coded as episodic future thinking training, and were further divided into food-related if the event cues related to food (or eating behaviour), goal-related if the event cues related to personal goals, and general if the manuscript did not explicitly state that event cues included food or goal characteristics.

Food novelty was coded as target food if the outcome measures used the same food (eg, cookie) as the food cues (eg, cookie) used in the training task and was coded as generalized food if it was not the same (eg, measured crisps consumption, but used chocolate cues in the training task; or measured crisps consumption, but used a variety of energy-rich food cues in the training task).

Food type was coded as unhealthy if the outcome measure used unhealthy food or high-calorie food (eg, sweets and cookies) and coded as healthy if the outcome measure used healthy food or low-calorie food (eg, fruits and vegetables) (see Table S3 for the detailed names of the unhealthy and healthy foods).

The 13-item quality scale for intervention studies developed by Thompson and colleagues[38] was used to assess the quality of the selected studies[6] (see Table S4 for study quality of each included study).

2.3 | Analytic strategy

The effect size measure of interest was the standardized mean difference between active intervention and control groups. Hedge's *g*, rather than Cohen's *d*, was used as the effect size for analysis, given that the former is a relatively unbiased estimate of the population standardized mean difference while the latter is a biased estimate.[39] Whenever possible, we calculated Hedge's *g* from the means, standard deviations (SD), and sample sizes presented in the article. When standard error (SE) but not SD was available, SD was estimated using the following equation: $SD = SE \times \sqrt{N}$. When data were available in figures only, we used the Plot Digitizer program[40] estimate means and SDs or SEs. We used the esc package in **R**, version 3.5.0 to calculate effect sizes.

It should be noted that most studies often report more than one outcome (eg, trained food and generalized food outcomes). Multiple outcomes are a problem for conventional meta-analytic methods, as averaging effect sizes within studies without accounting for their correlations can alter or obscure true effect size estimates.[41] Thus, we employed the meta-analytic technique of robust variance estimation to account for dependence between effect size estimates.[41]

For all of the following analyses, a negative effect size means that, relative to the control group, the training group increased unhealthy eating behaviour, increased calorie intake, or decreased healthy eating behaviour. A positive effect size indicates that, relative to the control group, the training group decreased unhealthy eating behaviour, decreased calorie intake, or increased healthy eating behaviour. In addition, because the outcome in these analyses is the standardized mean difference between groups (the effect size), a significant moderator means that the effect size estimate depends upon levels of that variable.

3 | RESULTS

3.1 | Preliminary analyses

3.1.1 | Study characteristics

The final sample consisted of 66 experiments—each of which is represented by *m*—assessing cognitive training effects on eating behaviour (m = 57) and weight loss (m = 13) in 5787 participants. Table S1 presents each study and its characteristics. There were total 153 effect sizes of cognitive training effects on eating behaviour, each of which is represented by *k*. Among effect sizes of cognitive training effects on eating behaviour, inhibition training effects were examined in 26 experiments (k = 64) with 2215 individuals. Attention bias modification training effects were examined in 11 studies (k = 43) with 1112 individuals. Approach/avoidance training effects were examined in studies 13 (k = 33) with 1504 individuals. Finally, episodic future thinking training effects were examined in nine studies (k = 13) with 432 individuals. Table S5 presents participant characteristics of each cognitive training on eating behaviour.

3.1.2 | Assessment of publication bias

To assess publication bias, we conducted Egger's test for funnel plot asymmetry in each cognitive training on eating behaviour (see Figure 2). Egger's test returned nonsignificant attention bias modification training ($t(11)$ = 1.10, P = .295), approach/avoidance training, ($t(13)$ = −0.07, P = .948), and episodic future thinking training, ($t(7)$ = 1.68, P = .137) indicating a lack of evidence for publication bias in these effects. However, it should be noted that a visual inspection of the plot for episodic future thinking training shows a trend towards publication bias; a lack of significance for the test of publication bias in this effect may be due to a lack of power. There was, however, evidence for publication bias in inhibition training effects on eating

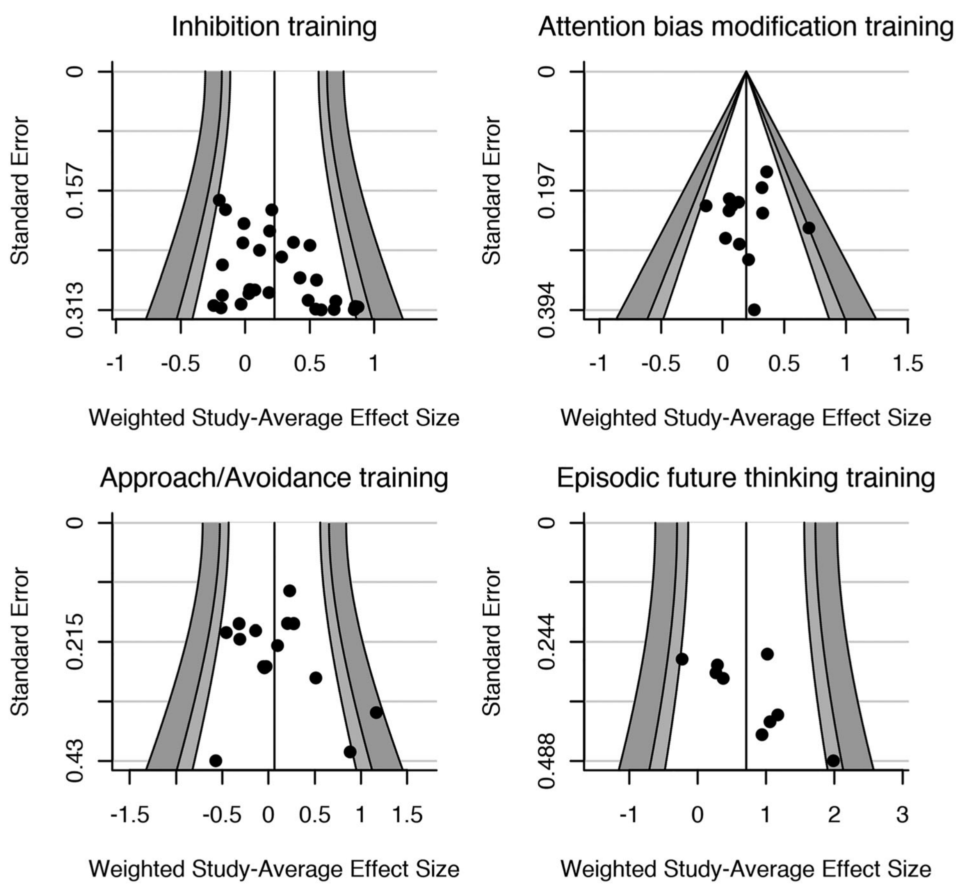

FIGURE 2 Funnel plots to ascertain evidence for publication bias in cognitive trainings on eating behaviour

behaviour, $t(27) = 2.56$, $P = .016$, with the estimate indicating that greater reductions in eating behaviour through inhibition training were more likely to be published than null or greater consumption effects of inhibition training on eating behaviour.

The significant evidence for publication bias in inhibition training effects prompts a concern that if more null effects of inhibition training would have been published, these studies might have reduced the effect to a trivial or negligible size. To examine this, we conducted trim and fill analyses for inhibition training effects on eating behaviour, and we calculated fail-safe N to quantify the number of studies required to reduce the effect of inhibition training on eating behaviour to a trivial effect size (eg, $-.10 < g < .10$). The trim and fill analysis for inhibition training effect on eating behaviour estimated that one unpublished study was missing from analyses of inhibition training effect on eating behaviour (estimated missing = 1; SE = 3.41). Although the actual effect may be weaker than what was estimated, the estimated effect of inhibition training effect on eating behaviour including the estimated one missing study was still significant, $P = .001$. Moreover, the fail-safe N analysis indicated that 37 studies with a mean null effect (eg, $g^+ = .00$) would be required to reduce the effect of inhibition training on eating behaviour to a trivial size, which constitutes nearly 50% more unpublished studies than published studies examining the effects of inhibition training on eating behaviour. Thus, despite some evidence for publication bias, the trim and fill analysis indicates

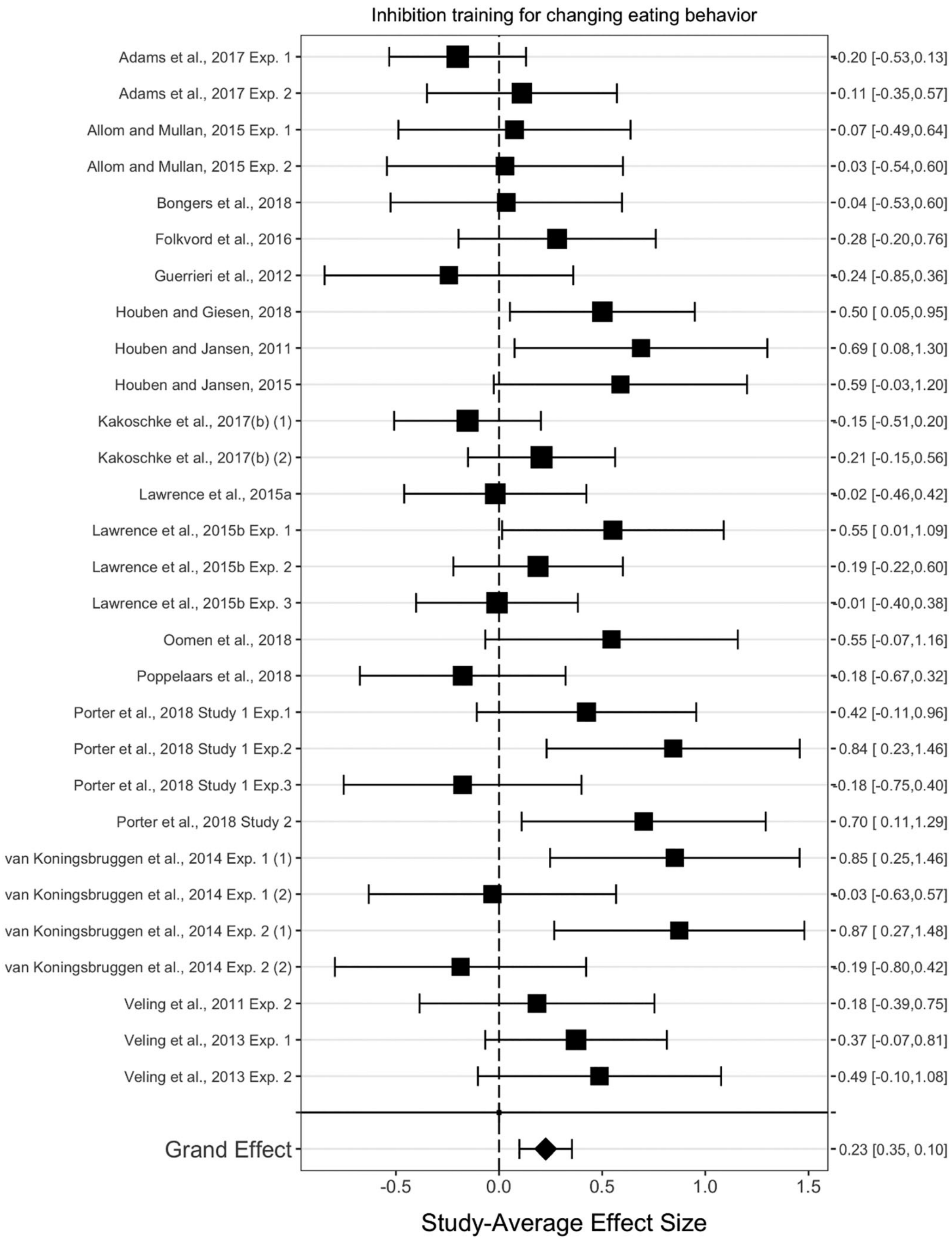

FIGURE 3 The effect of inhibition training on eating behaviour

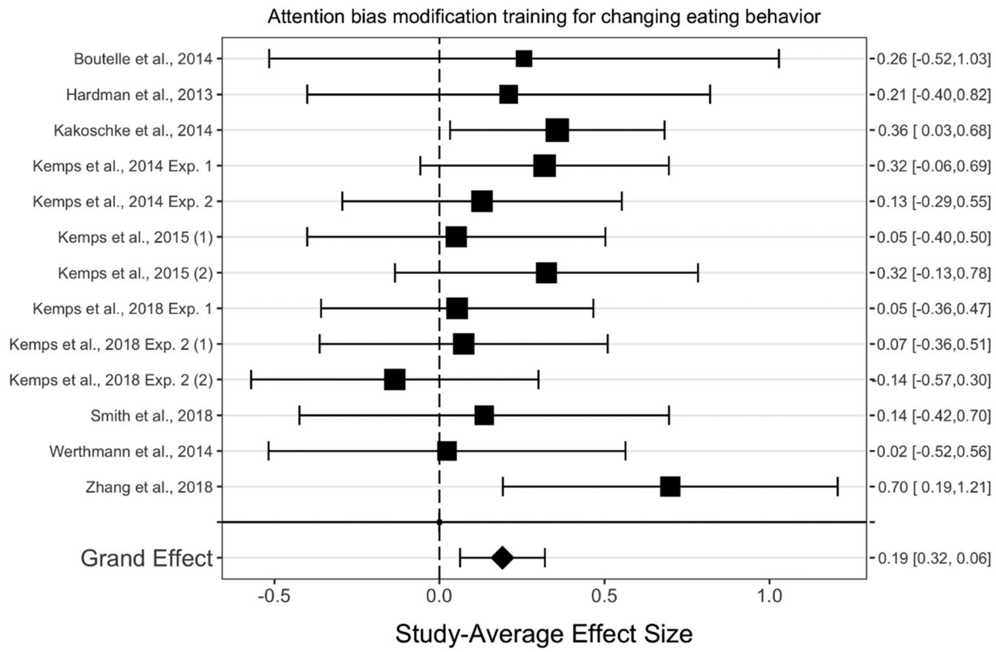

FIGURE 4 The effect of attention bias modification training on eating behaviour

that we can be confident that the effect of inhibition training on eating behaviour is a true effect.

3.1.3 | Achieved power analysis

To ensure that we had appropriate power to detect effects, we conducted power analyses for our random effects meta-analyses.[42†] Results showed that our analyses were well powered (Table S2), with the analyses of inhibition training, attention bias modification training, and approach/avoidance training obtaining greater than.80 power to detect even small effects (eg,$|g| \geq .20$). However, the analysis indicated that we did not have sufficient power to detect small effects in episodic future thinking training, though we achieved.95 power to detect a moderate effect. The minimum effect size that could be detected with.80 power for episodic future thinking training is$|g|= .38$.

3.2 | Primary analyses of cognitive training effects on eating behaviour

3.2.1 | Inhibition training.

The overall effect of inhibition training on eating behaviour (m = 26, k = 64, N = 2215) was significant ($g^+ = .226$, $t(26.9) = 3.63$, $P = .001$, 95% CI_g, 0.098-0.354) (see Figure 3), indicating that inhibition training changed participants' eating behaviour. There was low heterogeneity across these effects, $\tau^2 = 0.06$, indicating that the inhibition training effects on eating behaviour were relatively consistent across various conditions. Nonetheless, we explored the effects of moderators expected a priori to play an important role in the effects of inhibition training.

We expected training task to moderate inhibition training effect on eating behaviour, given the higher cue-inhibition contingency in the go/no-go task relative to stop signal task. As expected, inhibition training effects when the go/no-go task was used ($g^+ = .295$, $P = .0008$) were marginally significantly greater than inhibition training effects when stop signal task was used ($g^+ = .043$, $P = .650$), $t(11.8) = -2.17$, $P = .052$.

We also examined whether food novelty moderated inhibition training effects on eating behaviour, as previous work had suggested that the effect of cognitive training on food consumption could not be generalized to untrained food.[30] As expected, food novelty moderated the inhibition training effects, $t(13.1) = -3.53$, $P = .004$. When the outcome measure of eating behaviour used the same food as the food cues used in the training task, the inhibition training effect was significant ($g^+ = .331$, $P < .001$), whereas studies used generalized food in the outcome measure did not show a significant training effect ($g^+ = -.003$, $P = .969$).

3.2.2 | Attention bias modification training

The overall effect of attention bias modification training on eating behaviour (m = 11, k = 43, N = 1112) was significant ($g^+ = .191$, $t(11.5) = 3.25$, $P = .007$, 95% CI_g, 0.062-0.319) (see Figure 4), indicating that attention bias modification training changed participants' eating behaviour. There was low heterogeneity across these effects, $\tau^2 = 0.06$, indicating that the attention bias modification training effect on eating behaviour was relatively consistent across various conditions. Nonetheless, we explored the moderator effect of food novelty, as we had a priori expected this factor to play an important role in the effects of attention bias modification training.

†We used the average sample size for the intervention and control groups as the "typical" sample size per group as well as the observed heterogeneity (τ^2) to demonstrate the actual power of our analyses.

Unexpectedly, however, food novelty did not moderate the effect of attention bias modification training on eating behaviour, $t(9.8) = -0.67$, $P = .520$.

3.2.3 | Approach/Avoidance training

The overall effect of approach/avoidance training on eating behaviour ($m = 13$, $k = 33$, $N = 1504$) was not significant ($g^{+} = .064$, $t(12.3) = 0.65$, $P = .53$, 95% CI_g, −0.150 to 0.278) (see Figure 5), indicating that approach/avoidance training did not change participants' eating behaviour. There was low heterogeneity across these effects, $\tau^2 = 0.09$, indicating that the approach/avoidance training effects on eating behaviour are relatively consistent across various conditions. Nonetheless, we explored the potential moderating effect of food type, as this was expected a priori to moderate the effects of this intervention on eating behaviour.

As expected, food type moderated the effect of approach/avoidance training on eating behaviour, $t(12.3) = -2.36$, $P = .036$. When the outcome measure of eating behaviour used healthy food, the approach/avoidance training effect was marginally significant ($g^{+} = .272$, $P = .076$) (though note that there were only nine studies with healthy food as the outcome measure), whereas studies that used unhealthy food as the outcome measure showed a nonsignificant training effect ($g^{+} = -.150$, $P = .264$).

3.2.4 | Episodic future thinking training

The overall effect of episodic future thinking training on eating behaviour ($m = 9$, $k = 13$, $N = 432$) was significant ($g^{+} = .708$, $t(7.9) = 3.38$, P

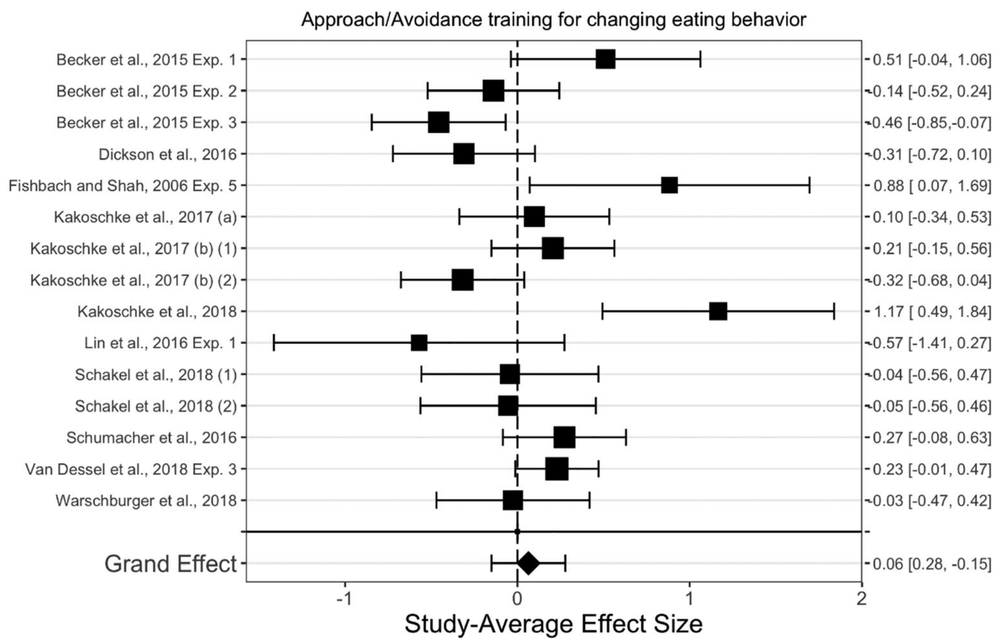

FIGURE 5 The effect of approach/avoidance training on eating behaviour

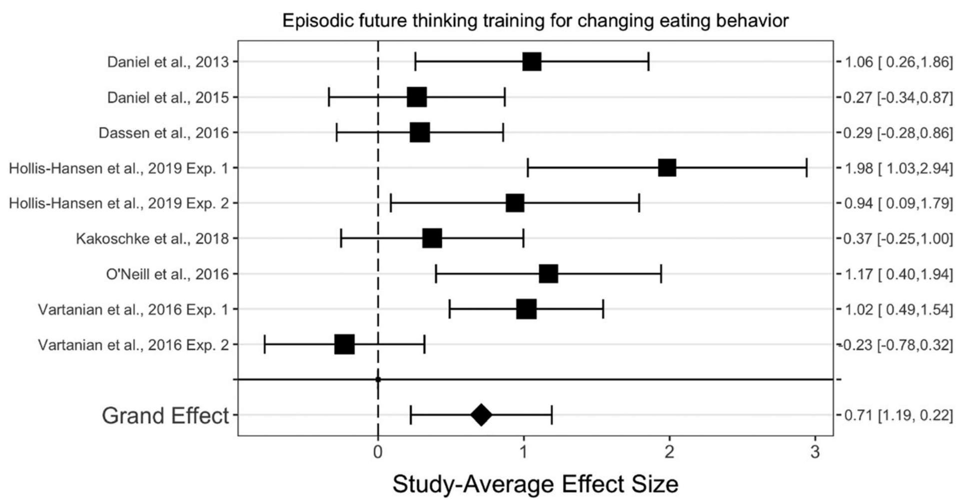

FIGURE 6 The effect of episodic future thinking training on eating behaviour

= .010, 95% CI_g, 0.224-1.19) (see Figure 6), indicating that episodic future thinking training changed participants' eating behaviour. There was moderate heterogeneity in these effects, τ^2 = 0.343, indicating that the training effect likely differed as a function of moderators.

We examined whether the type of episodic future thinking moderated the effect of episodic future thinking training on eating behaviour, given that some evidence suggested that the effect of episodic future thinking training may be most apparent when trained participants generate food-related events.[34] As expected, the type of episodic future thinking significantly moderated the effect of episodic future thinking training on eating behaviour, $t(6.2) = -3.73$, $P = .009$. Food-related episodic future thinking training significantly changed participants' eating behaviour ($g^+ = 1.31$, $t(3.7) = 5.94$, $P = .005$), whereas the effects of general-related and goal-related episodic future thinking training ($g^+ = .315$, $P = .142$) were not significant. Thus, the effect of episodic future thinking training on eating behaviour was moderated by the type of episodic future thinking, with more of an effect of the food-related episodic future thinking training.

3.3 | Primary evidence of cognitive training effects on weight loss

In addition to the examining the effects of cognitive training paradigms on eating behaviour, some studies have examined the effects of cognitive training paradigms on weight loss over time. However, as mentioned previously, there are too few studies to conduct a meta-analysis of the effects of cognitive training on weight loss. Therefore, we present these studies in Table 1 and summarize them in this section.

As Table 1 illustrates, the most consistent effects on weight loss were seen in food-specific inhibition training, with four of six inhibition training studies[43-47] finding that inhibition training contributed to weight loss. In contrast, all three studies examining the effects of working memory training on weight loss,[26,48,49] two of three studies examining the effects of attention bias modification training on weight loss,[46,50] all three studies examining the effects of approach/avoidance training on weight loss,[46,51,52] and one study examining the effects of episodic future thinking training on weight loss[53] did not find that the respective intervention contributed to weight loss. In addition, seven[26,44-48,52] of nine studies[26,44-50,52] did not find that the effects of the cognitive trainings on weight loss persisted after the cognitive training intervention was complete (eg, in follow-up assessments). In sum, current research provides preliminary support for the beneficial effect of food-specific inhibition training on weight loss from pre-intervention to post intervention, but more research is needed to test the cognitive training effect on weight loss before it can be recommended to include cognitive trainings for weight loss in a clinical context.

4 | DISCUSSION

In this review, we conducted a meta-analysis to examine the effects of cognitive training paradigms on eating behaviour, and we presented a

TABLE 1 Summary of the effect of cognitive trainings on weight loss

Trainings	Working Memory Training	Food-Specific Inhibition Training	Attention Bias Modification Training	Approach/Avoidance Training	Episodic Future Thinking training
Post intervention	−F (26, 48, 49*)	+F (43, 44), +F (45*), −F (46*), + F (Exp. 1) (47), −F (Exp. 2) (47)	+F (45*), −F (46*), −F (50)	−F (46*), −F (51)	+ F (in parents) (53), −F (in children) (53)
Follow-up	−F (1 or 6 mo) (26, 48), +F (2 mo) (49*), − F(3 mo) (49*)	−F (1 or 6 mo) (44, 45*), −F (1 mo) (46*), −F (1 wk) (Exp. 2) (47)	−F (6 mo) (45*), − F (1 mo) (46*), +F (3 mo) (50)	−F (1 mo) (46*), −F(6 and 12 mo) (52)	N/A

Note. *Studies using combined interventions: (45) food-specific inhibition training + attention bias modification training; (46) food-specific inhibition training + attention bias modification training + approach/avoidance training; (49) working memory training + general inhibition training.

Abbreviations: Exp., experiment; +F, positive findings; −F, negative findings; N/A, not available.

systematic review summarizing the effects of cognitive training on weight loss. We assessed the results of 66 experiments, which included a total of 5787 participants, that examined the effects of cognitive training paradigms targeting cognitive bias or executive control—namely, working memory training, inhibition training, attention bias modification training, approach/avoidance training, and episodic future thinking training. Although some meta-analyses have been conducted on this topic before,[35-37] our meta-analysis differed from these in several important ways. First, we included twenty-six studies not included in these prior meta-analyses. Second, and perhaps more importantly, we examined the effects of four different interventions in order to provide a more complete picture of the effects of cognitive training on eating behaviour. Finally, we conducted additional moderator analyses (eg, food novelty and food type) to examine potential contributions to heterogeneity in cognitive training effects.

We found that, overall, inhibition training, attention bias modification training, and episodic future thinking training significantly altered eating behaviour in a beneficial way; however, the effect of approach/avoidance training on eating behaviour was not significant. Moreover, we found that the effect of inhibition training was moderated by training task and food novelty (eg, whether the food was part of the training task), the effect of approach/avoidance training was moderated by food type (eg, whether the food was healthy or unhealthy), and the effect of episodic future thinking training was moderated by type of episodic future thinking (eg, whether the training was about food or general/goals). In addition, our literature review provided preliminary support for the effects of food-specific inhibition training on weight loss from pre-intervention to post intervention. However, given the limited studies of cognitive trainings on weight loss, more research is highly needed before firm conclusions can be drawn about the usefulness of cognitive training for weight control. Here, we first discuss the effects of each cognitive training on eating behaviour and then highlight questions for further research.

4.1 | Inhibition training

On average, inhibition training changed individuals' eating behaviour, with training task (eg, go/no-go vs stop signal) and food novelty (eg, whether or not the test food was used in the inhibition training task) moderating this main effect. The effect size found here was numerically smaller than previous meta-analysis focusing on the effects of inhibition training.[35,36] This numerical difference might have occurred because we only included studies examining the effects of inhibition training on eating behaviour, whereas other meta-analyses also included studies examining effects on drinking behaviour. Those drinking behaviour-related studies may have larger effect sizes since they usually used target drinks in the outcome measure. In addition, we also included two studies that with general inhibition training paradigms (eg, not food-specific paradigms). As expected, this type of training did not change individuals' eating behaviour, thus reducing the overall observed effect size. However, instead of excluding those two studies, we included those two studies in order to provide a more complete picture of the effect of inhibition training on eating behaviour, as a previous review did[7‡]. Like the effect of inhibition training on eating behaviour, our literature review also supported the idea that inhibition training may result in weight loss. However, for the inhibition training effect on weight loss, many questions remain regarding the repeatability of the training effect on weight loss and the role of individual differences (eg, motivation to lose weight and executive control). Clearly, more research is needed before firm conclusions can be drawn. A large, online trial of inhibition training—recruiting 32 000 participants—is ongoing and aiming to address some of these open questions.[54]

Two potential mechanisms are perhaps most likely to explain the effectiveness of inhibition training. First, consistently inhibiting responses towards no-go food cues may create direct food cue-stop associations, that is, automatic inhibition.[28] Second, food cues may be devalued after repeatedly inhibiting responses to them.[5,55] Support for those two potential mechanisms can be found in neuroimaging research. For example, Stice and colleagues found that, compared with changes observed in controls, inhibition and attention bias modification training reduced activations in reward regions (eg, putamen, insula) in response to high-calorie food images.[45] Similarly, an electroencephalography (EEG) study found that inhibition process may remain associated with no-go food images after inhibition training and become activated again (reflected by larger increases in theta power at frontal midline electrodes) during subsequent perception of these images.[56] Although this work is still nascent, these studies and others like them are helping to clarify the mechanisms that underlie the effects of inhibition training or cognitive training in the context of overeating and obesity.[6] Future work should therefore attempt to investigate the cognitive, neural, and/or biological mechanisms underpinning the effects of inhibition training or cognitive training more broadly on eating behaviour and weight loss.

Our results indicated that the effect of inhibition training on eating behaviour was marginally different depending upon (ie, was marginally moderated by) the task used to train inhibition (ie, the go/no-go vs stop signal task). In particular, inhibition training using the go/no-go task had marginally larger effects on eating behaviour than the training using the stop signal task, which is in agreement with a recent meta-analysis on health behaviour.[35] Relative to the usually 100% food and no-go contingency in go/no-go task, the stop signal task has lower food-stop contingencies. In addition, unlike the go/no-go task (which presents the stimulus and the signal at the same time), the stop signal task presents stop signals only after a certain delay. It is possible that lower food-stop contingencies and the delay of stop signal influence the strength of stimulus-stop response associations and further lead to the none significant changes of eating behaviour.[57] Finally, two studies using stop signal task involved no food stimuli, which may also contribute the nonsignificant effect, since general inhibition training has demonstrated minimal effects on behaviour change.[7]

‡Excluding the two studies using general inhibition training slightly increased the overall effect size of inhibition training (g^+ from .226 to .252).

The observed moderation of inhibition training effects by food novelty is consistent with several previous cognitive training studies that directly examined this factor. For example, Kemps and colleagues[30] found that attentional retraining of chocolate cues can successfully alter chocolate consumption (eg, chocolate muffin) but not generalized food consumption (eg, blueberry muffin). Using inhibition training on jelly candy cues, Folkvord and colleagues[29] found that the effect of inhibition training on jelly candy consumption was relatively larger than the effect on milk chocolate consumption. In addition, studies have shown that no-go food cues were devaluated compared with go and untrained when using food cues on both go and no-go trials in go/no-go training.[55,58] The current evidence indicated that the influence of inhibition training on eating behaviour was more effective when the outcome measure of eating behaviour used the same food as the food cues used in the training task. This lack of transfer effect was similar to observations from different fields (eg, training working memory to improve inhibition).[59] Therefore, because there are so many different types of foods and the evidence for transfer effects are limited, future inhibition training research should target high-calorie foods relevant to individuals in the target population, using those target foods as stimuli in inhibition training to achieve a stronger intervention effect.

4.2 | Attention bias modification training

We found that, on average, attention bias modification training changed individuals' eating behaviour. This effect follows from our understanding of how appetitive food contributes to attentional biases. In particular, through repeated exposure—especially in the current "obesogenic" environment—appetitive food acquires "incentive salience" via the rewarding effects of consuming those foods.[60] Further, this learned attention/approach bias to appetitive food, then steers behaviour towards acquiring and eating those foods.[9-12] Therefore, to reduce attention bias towards appetite but unhealthy food, attention bias modification training is designed to change attentional processing via consistent and systematic practice in diverting attention away from unhealthy food cues, directing attention instead towards healthy food cues. Indeed, the majority of studies (eight of 11) included in this meta-analysis found that attention bias modification training was effective at changing attention bias to food cues (eg, reducing attention bias to unhealthy food cues). Thus, by modifying attention to food, current evidence supported the idea that attention bias modification training alters eating behaviour. Unexpectedly, however, food novelty was not a significant moderator of the effect of attention bias modification training on eating behaviour. Importantly, though, there were too few studies to definitively conclude that food novelty is not a moderator of the effects of attention bias modification training on eating behaviour. Therefore, future studies and meta-analyses should continue to examine the potential moderating role of food novelty, in addition to other potential moderators of the effect of attention bias modification training on eating behaviour.

4.3 | Approach/avoidance training

We found no overall significant effect of approach/avoidance training on eating behaviour. Approach/avoidance training aims to reduce approach bias towards appetitive but unhealthy food and/or to increase approach bias towards healthy food. Although some of studies included in this meta-analysis found that approach/avoidance training was effective at changing approach bias towards food cues (eg, reducing approach bias to unhealthy food cues), no training effect was found on eating behaviour itself. This profile of effects differs from the effects of attention bias modification training. Like approach/avoidance training, the majority of attention bias modification training studies (eight of 11) changed attention bias towards food cues, but unlike approach/avoidance training, attention bias modification training also changed eating behaviour. It should be noted, though that most attention bias modification training studies were conducted using atypical samples—such as individuals with overweight/obesity, or women craving high-calorie food (eg, chocolate)—whereas most approach/avoidance training studies were conducted using typical samples (eg, healthy individuals). This difference in sample characteristics might help explain the differing effects of approach/avoidance training and attention bias modification training on eating behaviour, though future research should examine whether this is the case.

We found evidence for moderation of the effect of approach/avoidance training on eating behaviour by food type (eg, healthy vs unhealthy). In particular, although approach/avoidance training had no effect on unhealthy eating behaviour, it appeared to promote healthy eating behaviour. Some approach/avoidance training paradigms train not only an avoidance of unhealthy food but also an approach towards healthy food (eg, fruits and vegetables). This approach-healthy association might attach greater value to healthy food cues,[31] resulting in greater choice of healthy food. Indeed, studies[61,62] have found that participants chose to consume healthy foods more often when those participants were trained to respond to healthy food items without responding to other items. In short, although we did not find evidence for a main effect of approach/avoidance training on eating behaviour, some evidence suggests that approach/avoidance training focused on approach of healthy food might be an effective means of increasing the relative consumption of healthy food to unhealthy food.

4.4 | Episodic future thinking training

We found that, on average, episodic future thinking training changed individuals' eating behaviour. The proposed mechanism underpinning the effects of episodic future thinking training on eating behaviour is that imagining oneself at future events improves one's decision making (eg, delay discounting).[34] In the context of eating behaviour, by prompting individuals to vividly imagine their personal futures while they are making decisions about what to eat, they may be better able to connect how their eating behaviour today will influence their weight in the future, thereby helping them resist the temptation of appetitive food in the present. It should be noted, however, that there is some evidence that suggests the effects of episodic future thinking training on eating behaviour are heavily subject to demand characteristics, entailing that the effect of this intervention on eating behaviour may be inflated and may not generalize to long-term measures such as weight loss over time.[63]

We found that the type of episodic future thinking moderated the effect of episodic future thinking training on eating behaviour. That is, food-related episodic future thinking training significantly changed participants' eating behaviour, whereas the effects of general-related or goal-related episodic future thinking training did not. This result parallels findings of a recent study specifically designed to examine this potential moderator[34]; this study also found that only food-related episodic future thinking training reduced calorie intake. One potential explanation for this moderating effect is that unhealthy eaters are present-minded primarily or exclusively for food-related events, not others type events; therefore, only food-related episodic future thinking training may result in restricted caloric intake.[34]

4.5 | Limitations and future directions

This review and meta-analysis has limitations. First, only 13 studies investigated the effects of any of the five types of cognitive trainings on weight loss. Because of this, we were only able to qualitatively summarize these results (see Table 1) rather than conducting a meta-analysis on them. Given the promising results of cognitive trainings—especially food-related cognitive trainings—in changing eating behaviour, more studies should examine the effects of these trainings on weight loss, and a meta-analysis of the effects of these interventions on weight loss will be warranted when more studies have been conducted. Second, there may be additional moderators of cognitive training effects on eating behaviour that were unaccounted for in our analyses. In particular, small study set sizes prohibited us from conducting some moderator analyses. For example, we did not examine whether BMI or sex moderated the effect of each cognitive training on eating behaviour because most studies to date have only included female participants, and only 10 studies to date studied the effects of these interventions on individuals with overweight/obesity (see Appendix S2 for additional analyses of the moderating effect of BMI or weight status, combining all interventions). Relatedly, we analysed different moderators in different cognitive trainings since study set sizes in these moderators differed by intervention type. For example, we analysed the moderating role of food type (eg, healthy vs unhealthy) on the effect of approach/avoidance training since many studies included either/both of these food types; we did not analyse this potential moderator within the other training types because few studies considered the effects of these interventions on healthy (rather than unhealthy) eating behaviour. As such, we do not claim to present a complete picture of the moderators of cognitive training effects on eating behaviour. Third, studies included in our review mostly included samples consisting of young, predominantly female participants who were of normal weight, and these studies normally focused on the immediate effect of cognitive training. Therefore, it is largely unknown whether the cognitive training effects we observed will generalize to clinical populations (eg, individuals with obesity) or lead to persistent (eg, long-lasting) changes in eating behaviour and weight loss. In short, longer duration studies in clinical populations are needed to examine the generalizability of the results. Fourth, inhibition training showed small evidence for publication bias, and a visual inspection of the plot for episodic future thinking training shows a trend towards publication bias—a lack of significance for the test of publication bias in this effect may be due to a lack of power. Finally, only two had been conducted examining the effect of working memory training on eating behaviour, so we were unable to conduct a meta-analysis of this effect.

5 | CONCLUSION

In conclusion, our meta-analysis supported the idea that inhibition training, attention bias modification training, and episodic future thinking training can produce beneficial changes in eating behaviour. In contrast, no overall effect of approach/avoidance training on eating behaviour was found. Several marginal or significant moderators of these effects were identified. In particular, the effect of inhibition training was moderated by food novelty and marginally moderated by training task, the effect of approach/avoidance training was moderated by food type, and the effect of episodic future thinking training was moderated by type of episodic future thinking. Literature reviewed on cognitive training and weight loss provided preliminary support for the effects of food-specific inhibition training on weight loss from pre-intervention to post intervention. However, because most of the included studies focused on short-term outcomes and included relatively healthy participants, longer duration studies in clinical populations (eg, individuals with obesity) are needed to examine the generalizability of these results.

CONFLICT OF INTEREST

No conflict of interest was declared.

AUTHOR CONTRIBUTIONS

Yingkai Yang, Hong Chen, and Cheng Guo developed the concept for this article. Yingkai Yang analysed the data and wrote the manuscript. Grant S. Shields revised the manuscript and verified the analyses. Qian Wu and Yanling Liu provided critical revisions to the paper, and all authors read and approved the final version.

FUNDING INFORMATION

This research was supported by Fundamental Research Funds for the Central Universities, SWU1909106.

ORCID

Yingkai Yang https://orcid.org/0000-0002-2953-3543

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SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section at the end of the article.

How to cite this article: Yang Y, Shields GS, Wu Q, Liu Y, Chen H, Guo C. Cognitive training on eating behaviour and weight loss: A meta-analysis and systematic review. *Obesity Reviews*. 2019;1–14. https://doi.org/10.1111/obr.12916