The effects of mindfulness training on weight-loss and health-related behaviors in adults with overweight and obesity: A systematic review and meta-analysis

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Highlights

- Mindfulness training has been related to the adoption of healthier behaviors.
- We conducted a meta-analysis of RCTs testing mindfulness training for weight loss.
- Mindfulness decreases binge and impulsive eating and increases physical activity.
- No effects of mindfulness training on weight loss in adults with excess weight.
- Study design is a major source of heterogeneity in study effects.

Abstract

The aim of this study was to conduct a comprehensive quantitative synthesis of the effects of mindfulness training interventions on weight-loss and health behaviors in adults with overweight and obesity using meta-analytic techniques. Studies included in the analysis (n = 12) were randomized controlled trials investigating the effects of any form of mindfulness training on weight loss, impulsive eating, binge eating, or physical activity participation in adults with overweight and obesity. Random effects meta-analysis revealed that mindfulness training had no significant effect on weight loss, but an overall negative effect on impulsive eating (d = –1.13) and binge eating (d = –.90), and a positive effect on physical activity levels (d = .42). Meta-regression analysis showed that methodological features of included studies accounted for 100% of statistical heterogeneity of the effects of mindfulness training on weight loss (R^2 = 1,00). Among methodological features, the only significant predictor of weight loss was follow-up distance from post-intervention (β = 1.18; p < .05), suggesting that the longer follow-up distances were associated with greater weight loss. Results suggest that mindfulness training has short-term benefits on health-related behaviors. Future studies should explore the effectiveness of mindfulness training on long-term post-intervention weight loss in adults with overweight and obesity.

Keywords: mindfulness, body mass index, weight, binge eating, disordered eating, physical activity

1. Introduction

1.1. Obesity and health-related behaviors

According to a recent systematic review, 36.9% of men and 38.0% of women are overweight or obese [1]. According to the World Health World Health Organization [2], obesity results from an inappropriate energy balance between energy intake and energy expenditure. Negative affective states, such as acute stress and depressive mood, have been associated stronger drive to eat, which leads to excess weight gain and obesity [3-6]. Additionally, excessive food consumption is known to lead to excess weight and is also associated with sedentary behaviors [2, 7]. Binge eating disorder (BED) is the most prevalent eating disorder in individuals with overweight and obesity [8] and is characterized by recurrent and persistent episodes of uncontrolled and disinhibited eating sustained by psychological distress without any compensatory behavior [9].

Research has outlined that impulsive actions occur without considered deliberation or reflection [10, 11]. Such actions are the result of action patterns being initiated beyond an individual's awareness usually as a result of repeated exposure to cues and action pairings that are linked to reward (e.g., pleasure sensations, positive affect). The strength of these impulsive pathways are dependent on moderating factors such as context (e.g., the strength of the cue), and an individual's motivation (e.g., beliefs perceived benefits and costs of engaging in the action, beliefs about the behavior as a reward or stress management strategy) and capacity to override the impulsive pathway (e.g., levels of impulsivity, levels of self-control). The loss of control and disinhibited behaviors experienced during binge episodes therefore likely reflect a failure of the individual's capacity to regulate their impulses and may be dependent on a number of moderating factors [12]. Thus, impulsive eating refers to eating behaviors that are controlled by impulsive pathways to action that are manifested in binge eating behavior. In individuals with obesity, binge eating may be perceived as a compensatory behavior to cope with psychological distress [13], and has been shown to be stronger in patients with extreme levels of obesity [14]. Moreover, individuals with overweight and obesity tend to be more impulsive [15, 16] and report greater difficulties managing hedonic impulses [17] compared to normal weight individuals. Furthermore, excess weight has been associated to the tendency to prefer smaller immediate rewards over larger delayed ones in studies using classical or food-related delayed discounting tasks [18-20].

Recent research has demonstrated that low physical activity levels were also associated with increased risk of being overweight or obese [21], and evidence-based recommendations advocate physical activity programs may assist in reducing this risk [22]. While it is known that disordered eating and low physical activity level lead to weight gain, recent results have suggested that disinhibited eating, binge eating, brain responses to food cues, and food intake regulation may be attenuated by increased physical activity level [23, 24]. This means that physical activity may be an appropriate intervention to manage weight gain and disordered eating patterns.

1.2. Mindfulness-based interventions

There is growing interest in mindfulness training interventions to promote behaviors related to maintaining a healthy body weight and minimizing overweight and obesity such as dietary behavior and physical activity consistent with national recommendations [25]. Mindfulness training is commonly defined as an intervention that aims to foster non-judgmental and moment-to-moment awareness of the present experience [26]. Forman, Butryn, Hoffman, and Herbert [27] recommended the use of mindfulness-based cognitive-behavioral interventions to manage the physical and psychological health of obese patients in clinical contexts.

Mindfulness training is delivered in several treatment programs such as Mindfulness-Based Stress Reduction (MBSR) [26], Mindfulness-Based Cognitive Therapy (MBCT) [28],

Acceptance and Commitment Therapy (ACT) [29], Dialectical Behavioral Therapy (DBT) [30], and a large number of adapted interventions targeting specific outcomes or populations (e.g., Mindfulness-Based Eating Awareness Training) [31]. MBSR, the most studied mindfulness-based program, is an 8-week intervention with weekly 2-hour group sessions (held to teach meditation and provide collective feedback while participants share experiences) and daily 45-minutes home practice. Mindfulness-based interventions, such as MBSR and MBCT, have first been developed as cognitive behavioral therapies for mood and anxiety disorders [26, 32]. Acceptance-based (e.g., ACT) or other behavioral (e.g., DBT) interventions, which systematically include a mindfulness training, have been built to fit the needs of individuals seeking behavior change [33]. While mindfulness-based interventions focus on the awareness of thoughts, affects, and bodily sensations, acceptance-based and behavioral interventions focus on the acceptance of these cognitions, emotions, and sensations. Furthermore, Brown and Ryan [34] placed a strong emphasis on the self-regulatory function of mindfulness, which is characterized as "being attentive to and aware of what is taking place in the present moment" (p. 882).

In addition, studies showed that mindfulness skills (i.e., the ability to be non-judgmentally aware of the present experience) are linked to participation in health-related behaviors such as dietary behavior and physical activity consistent with national recommendations [25]. With regard to weight loss, studies investigating the effects of mindfulness training aiming at increasing physical activity in obese patients – who previously failed to lose weight after several attempts – have shown a post-treatment decrease in body mass index (BMI) compared to control groups [35, 36]. Results of these studies also indicate that previous failed attempts to lose weight are an important contributing factor to psychological distress in obese patients. Mindfulness training focusing on acceptance, awareness, and values, may help participants attend to the thoughts and feelings associated with these failures, and to develop new skills to manage them.

1.3. Previous reviews

To date, five reviews have investigated the effects of mindfulness training on disordered eating patterns and weight loss in obese patients [37-41]. Only one of these reviews conducted a meta-analytic synthesis of findings of randomized controlled trials (RCTs) [37], two conducted effect size analyses from baseline to post-intervention [39, 40], and two described the literature [38, 41]. Previous within-group results showed small effects of mindfulness-based interventions on body weight outcomes (Cohen's *d* range: –.17 to .26) [39, 40], small-to-large effects on binge eating (*d* range: .36 to 3.02) [39, 40], small-to-large effects on emotional eating (*d* range: .01 to .94) [39, 40], and moderate effects on external eating (*d* range: .53 to .70) [40]; previous between-group effects of mindfulness-based interventions on binge eating ranged from –1.20 to .27 (Hedge's *g*) [37]. Moreover, the number of included studies ranged from 12 to 21, depending on the selection criteria. Reviews investigating the effects of two standardized mindfulness-based interventions and excluding other techniques of mindfulness training resulted in smaller number of included studies [39, 41], while reviews investigating the effects of any mindfulness training on obesity-related disordered eating without targeting adults with overweight and/or obesity resulted in larger number of included studies [37, 40]. While previous reviews have focused on eating behaviors and weight changes, none have examined the overall effects of mindfulness training on physical activity.

1.4. Mechanisms of mindfulness implicated in obesity-related behaviors

Mindfulness- and acceptance-based interventions aim at training several skills such as awareness (i.e., noticing internal and external stimuli), disidentification (i.e., the ability to label thoughts as 'just thoughts' and to imagine having a distance from them), and acceptance (i.e., remain open to experiences without judgement). To understand the mechanisms of

mindfulness training to manage food craving, Lacaille and colleagues [42] conducted an experiment testing the effectiveness of each of the three core mindfulness skills. Results showed that disidentification may have the most important role in coping with food cravings when compared to awareness and acceptance. The ability to defuse from distractive food-related thoughts could be the most effective skill to reduce food cravings when compared to the ability to notice such thoughts or to accept them. Moreover, mindfulness includes a de-automation element (i.e., a skill to reduce automatic thoughts and behaviors) that can be effective in reducing of impulsive eating [43]. In addition, given that impulsive eating among individuals with obesity is related to difficulties to cope with psychological distress [13], and that mindfulness is related to the reduction of stress and depressed mood [44], mindfulness training may be beneficial in the reduction of disordered eating by helping individuals manage their psychological distress.

Mindfulness training (including acceptance-based interventions and behavioral interventions that include mindfulness training) has also been shown to increase physical activity level of sedentary individuals [35, 36, 45]. According to cross-sectional studies investigating the role of mechanisms of mindfulness implicated in behavior change (in the context of physical activity), findings suggest that mindfulness skills have a moderating role between pre-behavioral variables (e.g., intentions to change, motivational regulation) and physical activity level [46, 47]. Hence, bringing an increased and non-judgmental awareness toward physical activity behaviors may empower the effect of pre-behavioral variables on the performance of such behaviors. Similarly, while satisfaction with health behaviors facilitates engagement in such behaviors [48], Tsafou and colleagues [49] showed that mindfulness may be related to increased satisfaction in so far as it presumably enhances the favorable processing of physical activity experiences (either positive, or negative) which conjointly lead to enhanced satisfaction with physical activity.

1.5. The present study

While there is growing research on the effectiveness of mindfulness training programs in promoting better health-related behaviors in individuals with overweight and obesity, a meta-analytic synthesis of the research examining its effectiveness on such behaviors across multiple studies has not been conducted. The purpose of the current review is to conduct a comprehensive quantitative synthesis of RCTs of the effects of mindfulness training on health behaviors of adults with overweight and obesity using meta-analytic techniques. The current study will advance understanding by providing quantitative estimates of the effect size of mindfulness techniques on eating patterns in individuals with excess weight as well as physical activity in addition to weight loss. Our systematic review and meta-analysis of the current literature test the effectiveness of interventions adopting any form of mindfulness training provided in cognitive and behavioral interventions on weight loss, impulsive eating, binge eating, and physical activity, among overweight and obese individuals. It will make a unique contribution as only one previous systematic review in this field focused exclusively on RCTs and meta-analyzed the effects of the interventions, and none focused on physical activity. However, our review will contribute to understand the role of mindfulness in weight management (i.e., energy balance) by statistically correcting for the methodological artifact of sampling error and testing the effects of mindfulness on eating and exercise behaviors across the research literature.

Furthermore, meta-regression analysis of covariates will bring information regarding methodological and design features that may affect the effectiveness of mindfulness training programs on weight loss. To this end, type of intervention (behavioral or non-behavioral), primary focus of intervention (weight loss or eating behavior), intervention duration (less or more than 3 months), participants' condition (binge or non-binge eaters), and follow-up distance from post-intervention (less or more than 3 months) have been selected as potential

moderators of the effects of mindfulness training on weight loss and related health behaviors. It was hypothesized that behavioral interventions (e.g., ACT) aiming at reducing weight loss would be more effective for weight loss in so far as such programs primarily aim at changing weight-related behaviors with mindfulness-based techniques. Likewise, it was expected that interventions targeting eating behaviors of those who endorse recent binge eating behavior would be more effective in the reduction of binge and impulsive eating. Moreover, longer intervention durations and follow-up distances may attenuate the effects of mindfulness training programs.

2. Material and methods

2.1. Study selection

Studies were selected to inclusion in the current analysis if they satisfied the following criteria: (a) adopted an RCT design, (b) used any form of mindfulness training as intervention, (c) were conducted on adult participants (aged over 18 years) with a BMI of at least 25 kg/m^2, and (d) included weight, impulsive eating, binge eating, or physical activity level as an outcome measure. Studies including patients with comorbid physical or psychological disorders were eligible for inclusion. No restriction was applied on the primary focus of the intervention (e.g., weight loss, reduction of caloric intake), administration modality, duration, frequency, and predominance of the mindfulness training in the interventions. Treatment as usual, wait-list, and information-only programs were eligible control groups. The primary outcome measure was the change in BMI from baseline to post-intervention. Secondary outcomes were impulsive eating including disinhibited and uncontrolled eating (measured by self-reported questionnaires such as the Three-Factor Eating Questionnaire [50] or experimental tasks such as delay discounting tasks specific to food items), binge eating (measured by self-reported scales such as the Binge Eating Scale [51], or semi-structured diagnostic interviews aiming at checking relevant symptoms), and changes in physical activity level, from baseline to post-intervention.

We only included articles published in English-language journals. MEDLINE (PubMed), EMBASE (ScienceDirect), PsycINFO, and CENTRAL (The Cochrane Library) were searched up to February 2016, with no restriction applied on begin date range. The literature search was constructed around search terms for obesity (obesity, overweight, weight, metabolic syndrome, adiposity), mindfulness (mindfulness, acceptance, meditation, awareness), disordered eating (binge eating, impulsive eating, disinhibition, uncontrolled eating, disordered eating, calorie intake), and exercise (exercise, physical activity, sport, energy expenditure) in full texts words. The search strategy was adapted for each database as necessary. Potential additional studies were searched through the reference lists of included trials. The selection process for studies included in this review is shown in Fig 1.

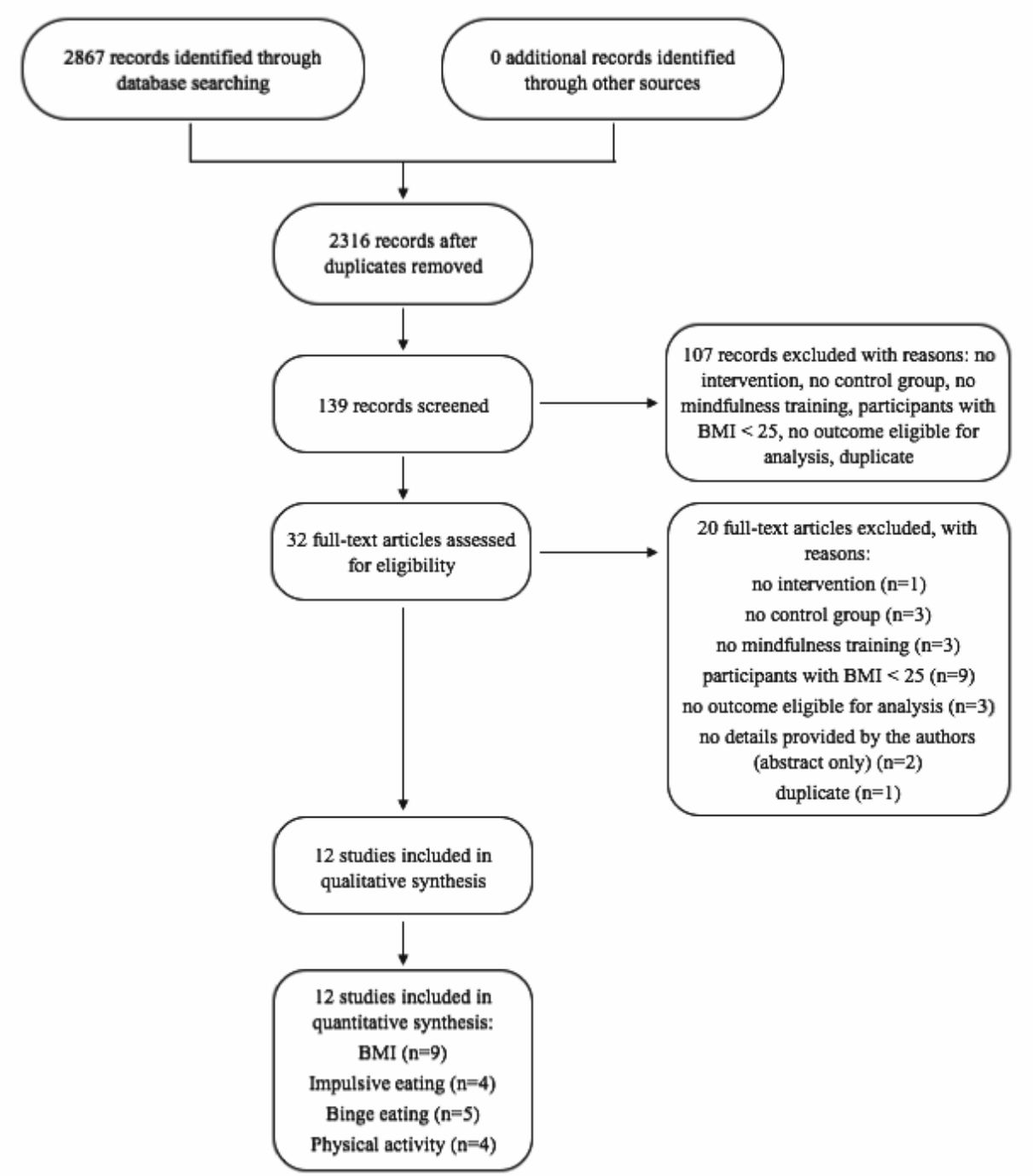

Fig 1. Flow diagram for the selection of studies.

2.2. Data extraction

First, titles and abstracts were screened to identify potentially eligible studies. Second, full texts of all potentially relevant articles were investigated. Two authors independently screened the articles to identify studies that met inclusion criteria, and conflicts of opinion were discussed with a third author until consensus was reached. Using a standardized data extraction form, two independent investigators extracted and tabulated all data with any disagreements resolved by discussion among the investigators, or, if required, by a third party. When necessary, the primary authors of the trials were contacted for additional information. Data extracted from the studies and study characteristics are available in Table 1.

Table 1. Characteristics of the included studies.

Study ID	Participants				Intervention	Focus of the intervention	Control group	Assessments	Assessment times (from baseline)	Main findings
	N (%women)	Mean BMI (SD)	Mean age (SD)	Condition						
Alberts 2010	19 (90%)	31.3 (4.1)	51.9 (12.8)	Patients with overweight and obesity recruited in a community centre	Manual based mindfulness intervention for food craving (7 weeks): weekly group sessions, daily 1.5h homework, exercise and dietary counselling (10 weeks)	Eating behaviors	Exercise and dietary counselling (10 weeks)	Weight: BMI IE: G-FCQ-T BE: none PA: none Mindfulness: none	Baseline 7 weeks	Participants in the mindfulness-based intervention for food craving reported lower food cravings compared to participants in the control group.
Blevins 2009	41 (100%)	29.6 (1.9)	20.7 (1.4)	Students with overweight and obesity	MBSR (8 weeks): weekly group sessions (2h), daily 45min homework, eating components, physical activity recommendation, standard behavioral treatment	Eating behaviors	Standard behavioral treatment (8 weeks): weekly group sessions (2h), homework	Weight: BMI IE: none BE: QEWP-R PA: none Mindfulness: none	Baseline 8 weeks 5 months	Standard behavioral treatment plus mindfulness training did not produce greater improvements than standard behavioral treatment alone.
Daubenmier 2012	47 (100%)	31.4 (4.8)	40.8 (NA)	Individuals with overweight and obesity	Adapted MBSR (MB-EAT, 4 months): weekly group sessions (2.5h), daily 30min homework, nutrition and exercise information (2h)	Eating behaviors	Wait-list, nutrition and exercise information (2h)	Weight: BMI IE: none BE: none PA: none Mindfulness: none	Baseline 4 months	Decreased levels of restriction, and fat and glucose intake were associated with increased telomerase activity in the mindfulness training group.

Davis 2009	71 (89%)	32.9 (3.7)	45.1 (8.3)	Individuals with overweight and obesity	Adapted mindfulness intervention for weight loss (24 weeks): weekly group sessions (30min), daily homework, standard behavioral weight loss intervention	Eating behaviors and physical activity (weight loss)	Standard weight loss intervention (24 weeks): weekly group sessions (30min)	Weight: BMI IE: Eating Inventory BE: none PA: PPAQ (kcal/week) Mindfulness: MAAS	Baseline 24 weeks	The behavioral intervention resulted in weight loss and improvements in physical activity and eating behaviors; however, additional mindfulness training did not improve outcomes.
Fletcher 2012	72 (83%)	35.5 (SE = 0.1)	52.6 (11.8)	Patients with overweight and obesity recruited in a weight loss clinic	ACT workshop (1-time, 6h)	Weight loss and health	Wait-list	Weight: BMI IE: none BE: none PA: IPAQ Mindfulness: AAQ-II	Baseline 3 months	Intervention group showed improvement in physical activity level and weight loss; however, there were no significant difference with the control group.
Hendrickson 2013	102 (72%)	26.1 (NA)	25.5 (8.6)	Students with overweight and obesity	MBSR initiation (1-time, 50min)	Eating behaviors	Nutrition information (1-time, 50min)	Weight: none IE: Delay discounting task BE: none PA: none Mindfulness: none	Baseline 3 days	Attendance to a mindful eating session led to more self-controlled and less risk-averse discounting patterns for food.
Kristeller 2014	140 (88%)	40.3 (range: 26-78)	46.6 (range: 20-74)	Individuals with overweight and obesity diagnosed with BED	MB-EAT (2 months): 9 weekly group sessions (30min) and 3 monthly boosters (30min), daily 20min homework	Eating behaviors	Wait-list	Weight: BMI IE: TFEQ BE: BES PA: none Mindfulness: none	Baseline 3 months 6 months	An eating awareness training lead to decreased binge eating and disordered eating.
Lillis 2009	84 (90%)	33.0 (7.1)	50.8 (11.3)	Individuals with overweight and obesity	ACT workshop (1-time, 6h): homework (ACT workbook)	Weight loss and health	Wait-list	Weight: BMI IE: none BE: none PA: none Mindfulness: AAQ-II	Baseline 3 months	Acceptance-based intervention can enhance current efforts to control weight without any focus on weight control per se.
Masson 2013	60 (88%)	38.0 (8.8)	42.4 (10.5)	Individuals with overweight and obesity diagnosed with BED	Self-help manual based DBT (13 weeks): initiation (45min), 6 biweekly phone calls (20min)	Eating behaviors	Wait-list	Weight: none IE: none BE: Binge episodes frequency (28 days) PA: none Mindfulness: none	Baseline 13 weeks	Low intensity self-help DBT reduced binge episodes frequency of individuals diagnosed with BED.

McIver 2009	71 (100%)	34.1 (6.4)	41.1 (10.3)	Individuals with overweight and obesity diagnosed with BED	Yoga (12 weeks): weekly group session (60min), daily 30min homework, meditation	Eating behaviors	Wait-list	Weight: BMI IE: none BE: BES PA: IPAQ Mindfulness: none	Baseline 12 weeks	Home-based yoga intervention increased physical activity, and decreased binge eating and weight.
Miller 2012	52 (64%)	36.2 (1.2)	54.0 (7.6)	Individuals with overweight and obesity with diagnosed type 2 diabetes mellitus	MB-EAT (3 months): 8 weekly and 2 biweekly group sessions (2.5h), daily 20min homework	Eating behaviors and diabetes management	Information and education for diabetes (3 months): 8 weekly and 2 biweekly group sessions (2.5h)	Weight: BMI IE: none BE: none PA: MPAQ Mindfulness: none	Baseline 3 months 6 months	MB-EAT led to improvement in dietary intake, weight loss, and glycemic control.
Weineland 2012	39 (90%)	27.2 (NA)	43.1 (range: 25-59)	Patients with obesity post-bariatric surgery recruited in a local center	Self-help ACT (6 weeks): 2 face-to-face sessions (first and last, 1.5h), weekly telephone support (30min)	Eating behaviors	Dietary guidelines, telephone support if needed	Weight: none IE: none BE: SBEQ PA: none Mindfulness: none	Baseline 6 weeks	Self-help ACT intervention improved eating disordered behaviors and acceptance for weight related thoughts and feelings, as compared to a TAU group.

Body mass index (BMI) is expressed in kg/m^2. SD: standard deviation. NA: not available. BED: binge eating disorder. ACT: acceptance and commitment therapy. DBT: dialectical behavioural therapy. MBSR: mindfulness-based stress reduction. MB-EAT: mindfulness-based eating awareness training. TAU: treatment as usual. IE: impulsive eating. BE: binge eating. PA: physical activity. G-FCQ-T: general food craving questionnaire-trait. TFEQ: three-factor eating questionnaire. QEWP-R: questionnaire of eating and weight patterns-revised. BES: binge eating scale. SBEQ: subjective binge eating questionnaire. PPAQ: Paffenbarger physical activity questionnaire. IPAQ: international physical activity questionnaire. MPAQ: modifiable physical activity questionnaire. MAAS: mindful attention awareness scale. AAQ-II: acceptance and action questionnaire-II.

Risk of bias was independently assessed by two authors using the Cochrane risk of bias assessment tool [52]. The risk of bias assessment tool assesses risk of bias in the included trials for the following domains: selection, performance, attrition, reporting, detection, and other. For each domain, risk of bias was judged as 'low', 'unclear', or 'high'. Conflicts of opinion were discussed with a third author until consensus was reached.

2.3. Statistical analysis

Data for the primary outcome variable, change in BMI, were expressed as a mean difference (MD) because BMI was measured using identical units (kg/m^2) across studies. Data for secondary outcomes, impulsive eating, binge eating, and physical activity levels, were expressed as Cohen's *d*, because different measurement tools were used to assess each variable. Data from original articles were transformed as MD and Cohen's *d* by using Cochrane guidelines in each case (e.g., transforming standard errors into standard deviation, calculating standard deviations of original MD if not provided) [53]. MD and Cohen's *d* were analyzed using random effects because of small sample sizes in the included studies. We contacted the authors to obtain relevant missing data, if feasible.

The magnitude of between-study heterogeneity after correcting for statistical artifacts evaluated by the I^2 statistic with levels below 40%, between 30% and 60%, between 50% and 90%, and greater than 75% equating to low, moderate, substantial, and high levels of heterogeneity, respectively [53]. The χ^2 test was used to assess whether the proportion of the total variability across studies was statistically significantly different to the proportion of variance attributable to the methodological artifact for which we corrected i.e. sampling error. A statistically significant finding indicates that a substantial proportion of the variance is attributable to factors other than sampling error and is indicative of potential extraneous moderators of the effect. Given the poor power of this test when only a few studies or studies with low sample sizes are included in a meta-analysis, a *p*-value below or equal to .10 was regarded to indicate statistically meaningful difference from zero [53]. We used funnel plots to assess the potential existence of small study bias in cases where we could include 10 or more studies to investigate a particular effect. We statistically summarized data when the data were available, sufficiently similar, and of sufficient quality [53]. We performed analyses according to the statistical guidelines contained in the latest version of the *Cochrane Handbook for Systematic Reviews of Interventions* [53].

In addition, when substantial or high heterogeneity was present, we carried out meta-regression analyses [54] of the following moderator variables: type of intervention (i.e., behavioral vs. non-behavioral), main focus of the intervention (i.e., disordered eating vs. weight loss), duration of the intervention (i.e., less than 3 months vs. more than 3 months), participants' condition (i.e., binge eaters vs. non-binge eaters), distance of the outcome measure from baseline (i.e., less than 3 months vs. more than 3 months). Moderator variables were selected among study design characteristics as potential methodological factors that could impact effect sizes. All analyses were conducted using R [55] and the 95% confidence intervals were used to establish whether effect size statistics were statistically significantly different from zero.

3. Results

3.1. Description of studies

The literature review resulted in 2867 records being identified that were subsequently screened for eligibility. Application of our exclusion criteria resulted in a total of 12 studies included in the meta-analysis [31, 35, 43, 56-64]. In total, 20 studies were excluded from the review for the following reasons: lack of randomized controlled design or mindfulness intervention, participants had normal weight (BMI < $25kg/m^2$) or lack of outcome eligible for inclusion.

Baseline characteristics for the studies included in the meta-analysis are presented in Table 1. Trial durations across the included studies ranged from 3 days to 6 months. There were a total of 626 participants across the 12 trials, out of which 315 were randomized to intervention group and 311 to control groups. The percentage of participants who completed the studies ranged from 55% to 100%. Trials were conducted with the participation of adults with overweight and obesity exclusively. Percentage of women in the included studies ranged from 64% to 100%, with three trials including only female participants [56, 57, 62]. Mean age of the participants ranged from 20.7 to 54 years old. Mean BMI at baseline ranged from 26.1 to 40.3 kg/m^2. Out of the 12 selected trials, three included participants with diagnosed binge eating disorders [31, 61, 62], two included students [56, 60], one included participants with diagnosed type 2 diabetes mellitus [63], one included obese individuals after bariatric surgery [64], and five included individuals with overweight and obesity who wanted to lose weight [35, 43, 57-59].

Descriptions of interventions for the included trials are shown in Table 1. Out of the 12 trials that tested an intervention including mindfulness training, three interventions were based on mindfulness-based eating awareness training (MB-EAT) [31, 57, 63], three were based on acceptance and commitment therapy [35, 59, 64], two were adapted for food craving or weight loss [43, 58], one was mindfulness-based stress reduction (MBSR) [56], one was an initiation to MBSR [60], one was dialectical behavioral therapy [61], and one was yoga and meditation [62]. Eight interventions aimed at improving eating behaviors [31, 43, 56, 57, 60-62, 64], two focused on weight loss and health [35, 59], one aimed at reducing caloric intake and increasing exercise behavior [58], and one focused on eating behaviors and diabetes management [63]. Two trials tested a self-help intervention [61, 64]. Four trials tested mindfulness training as supplementary care, adding cognitive behavioral components and counseling (exercise, dietary, nutrition) [43, 56-58]. Length of intervention in the trials ranged from 50 minutes to 24 weeks.

The primary outcome variable in the current view was change in BMI at post-intervention. Out of the nine trials that measured BMI at post-intervention, two trials assessed BMI after two months [43, 56], four trials assessed BMI after 3 months [35, 59, 62, 63], one trial assessed BMI after 4 months [57], and two trials assessed BMI after 6 months [31, 58]. The four trials that measured impulsive eating used four different tests: three used self-report surveys [31, 43, 58], and one used a delayed-discounting task [60]. The five trials that measured binge eating used four different self-reported outcomes [31, 56, 61, 62, 64]. The four trials that measured physical activity used three different self-reported questionnaires [58, 59, 62, 63]. Three trials measured self-reported mindfulness skills in participants: two trials measured acceptance [35, 59], and one trial measured dispositional mindfulness [58]. Details on the outcomes are described in Table 1.

3.2. Risk of bias in included studies

Risk of bias of the included studies is described in Table 2. Nine trials (75%) had some methodological weaknesses according to the criteria applied. Only three (25%) trials reported adequate methods for sequence generation. Six trials (50%) reported adequate methods for allocation; the other six did not report any information regarding allocation and randomization. Only one study (8%) reported the methods of blinding of participants and personnel, and it was judged as a high risk of bias. Three studies (25%) reported adequate methods of blinding of outcome assessment. Four studies (33%) reported adequate methods for imputing missing data, two (17%) reported inadequate methods, and the six other (50%) did not report any information regarding the missing data. Selective reporting was at low risk of bias in all of the included studies. Four studies (33%) were at high risk of bias, because they offered compensation for participation.

Table 2. Risk of bias summary.

Study ID	Random sequence generation	Allocation concealment	Blinding of participants and personnel	Blinding of outcome assessment	Incomplete outcome data	Selective reporting	Other bias
Alberts 2010	Low	?	High	?	?	Low	Low
Blevins 2009	High	Low	?	?	?	Low	Low
Daubenmier 2012	High	?	?	?	?	Low	High
Davis 2009	High	?	?	Low	?	Low	High
Fletcher 2012	High	?	?	?	?	Low	High
Hendrickson 2014	Low	?	?	?	?	Low	High
Kristeller 2014	High	Low	?	?	Low	Low	Low
Lillis 2009	High	Low	?	Low	Low	Low	Low
Masson 2013	High	Low	?	Low	High	Low	Low
McIver 2009	High	Low	?	?	High	Low	Low
Miller 2012	High	Low	?	?	Low	Low	Low
Weineland 2012	Low	?	?	?	Low	Low	Low

Question marks (?) denote categories for which risk of bias could not be ascertained from the data reported.

3.3. Effects of interventions

Given the relatively small number of included studies in analyses of each outcome, meta-regression analyses of potential moderators were conducted when more than one study was part of a subgroup (e.g., analyses of the moderator 'type of intervention' were not conducted when only one study was testing a 'non-behavioral' intervention).

3.3.1. Primary outcome: change in BMI.

Overall, the change in BMI from baseline to post-intervention in RCTs did not show a statistically significant effect of mindfulness training in adults with overweight and obesity (MD = –.15 kg/m^2; 95% CI –.59 to .29; p = .50). Assessment of heterogeneity showed statistically significant substantial levels of heterogeneity among the trials assessing BMI at baseline and post-intervention (I^2 = 63%; p < .05). The forest plot of BMI change in the included studies is displayed in Fig 2. Maximum likelihood meta-regression of covariates showed that the differences in study designs (i.e., following five criteria called moderators) were responsible for substantial statistical heterogeneity between studies. The model predicting weight loss with the five moderators explained 100% of initial heterogeneity (τ^2 = 0; SE = .04; QE(3) = 6.47; p = .09), and distance of the administration of the outcome measure from baseline was the only significant predictor, suggesting that longer term outcome measures were associated with larger weight loss (Table 4).

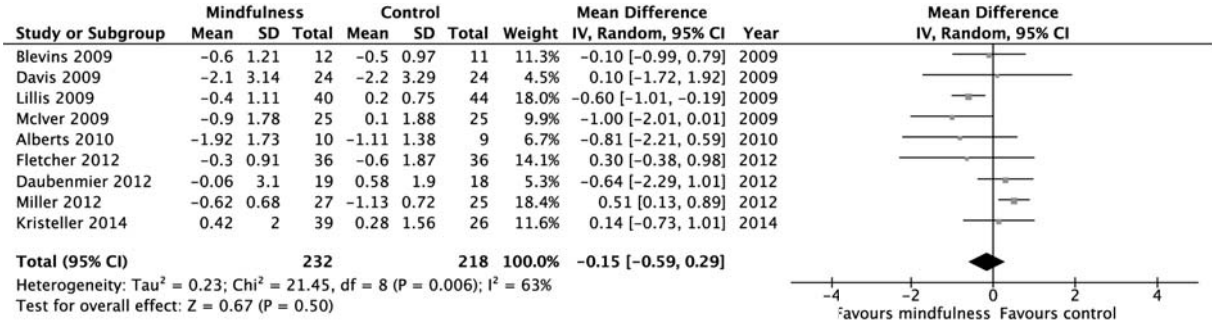

Fig 2. Forest plot of comparison: BMI change from baseline to post-intervention.

3.3.2. Secondary outcomes.

3.3.2.1. Impulsive eating.

Overall, post-intervention impulsive eating was statistically significantly lower in the intervention groups than in the control groups (p < .01) (see Table 3). Moreover, mindfulness training significantly reduced impulsive eating from baseline to post-intervention in the intervention groups (d = –1.15; 95% CI –1.91; –.38; p < .01)[1]. These results show that the effects of mindfulness training on impulsive eating are statistically significant and large in the included studies (i.e., d > .80) [65]. Assessment of heterogeneity showed statistically significant substantial-to-high heterogeneity among the trials (p < .001). Maximum likelihood meta-regression of covariates showed that the differences in study designs (i.e., following two criteria called moderators) were responsible for substantial-to-high statistical heterogeneity between studies. The model predicting impulsive eating with two moderators (focus of intervention and participants' condition) explained 18.34% of initial heterogeneity (τ^2 = 0.93;

[1]We conducted an additional analysis to test the effects of mindfulness training on impulsive and binge eating as separate outcomes and as a single outcome aggregated across studies. Results indicated that the effects of intervention on measuring 'impulsive eating' (k = 4, d = –1.13 (–1.93; –.33), I^2 = 85%) and 'binge eating' (k = 5, d = –.90 (–1.52; –.28), I^2 = 79%) were comparable to results for studies measuring either outcome (k = 9, d = –1.05 (–1.73; –.32); I^2 = 90%). These results indicated that the effects were no different across these outcomes. We have, however, retained the distinction given that this distinction has been made in the literature.

SE = .76; QE(1) = 18; $p < .001$); however none of the moderators was significantly associated to reductions in impulsive eating (Table 4).

3.3.2.2. Binge eating.

Overall, binge eating at post-intervention was statistically significantly lower in the intervention groups than in the control groups ($p < .01$) (see Table 3). Moreover, mindfulness training statistically significantly decreased binge eating from baseline to post-intervention in the intervention groups ($d = –1.26$; 95% CI –1.89 to –.63; $p < .001$). Subgroup analyses revealed that participants' condition and type of intervention were effective moderators (see Table 3): mindfulness training was significantly effective on the reduction of binge eating in binge eaters (and non-significant in non-binge eaters) and behavioral interventions (e.g., ACT) showed significant effects on the reduction of binge eating while other interventions (e.g., MB-EAT) showed non-significant results. These results show that the effects of mindfulness training on binge eating are statistically significant and large in the included studies (i.e., $d > .80$) [65]. Assessment of heterogeneity showed statistically significant and substantial-to-high levels of heterogeneity among the trials ($p < .001$). Maximum likelihood meta-regression of covariates showed that the differences in study designs (i.e., following two criteria called moderators) were responsible for substantial-to-high statistical heterogeneity between studies. The model predicting binge eating with two moderators (type of intervention and participants' condition) explained 65.64% of initial heterogeneity ($\tau^2 = 0.12$; SE = .14; QE(2) = 10.57; $p < .01$). Participants' condition was significantly associated with larger reductions in binge eating, which suggests that individuals suffering from BED benefit more from mindfulness training to reduce the tendency to binge eat (Table 4).

Table 3. Effect sizes (d) of secondary outcomes in the included studies between intervention and control groups at post-intervention.

Outcome	Moderator	Groups	*d*	95% *CI*	Number of studies	Number of participants (in intervention group)	Inter-study heterogeneity (I^2 statistic)
Impulsive eating			–1.13*	(–1.93 to –.33)	4	227 (120)	85%
	Type of intervention	Non-behavioral	NA	NA	4	NA	NA
		Behavioral	NA	NA	0	NA	NA
	Focus of the intervention	Eating behaviors	–1.49*	(–2.66 to –.31)	3	179 (96)	89%
		Weight loss	–.49	(–1.07 to .08)	1	48 (24)	NA
	Intervention duration	< 3 months	–1.49*	(–2.66 to –.31)	3	179 (96)	89%
		> 3 months	–.49	(–1.07 to .08)	1	48 (24)	NA
	Participants' condition	Non-binge eaters	–1.20*	(–2.31 to –.08)	3	162 (81)	87%
		Binge eaters	–1.20*	(–1.74 to –.66)	1	65 (39)	NA
	Follow-up distance	< 3 months	–2.00	(–5.30 to 1.29)	2	114 (57)	94%
		> 3 months	–.85*	(–1.55 to –.16)	2	113 (63)	68%
Binge eating			–.90*	(–1.52 to –.28)	5	231 (121)	79%
	Type of intervention	Non-behavioral	–.95	(–2.09 to .20)	3	138 (76)	88%
		Behavioral	–.79*	(–1.22 to –.37)	2	93 (45)	0%
	Focus of the intervention	Eating behaviors	NA	NA	5	NA	NA
		Weight loss	NA	NA	0	NA	NA
	Intervention duration	< 3 months	–.93*	(–1.76 to –.10)	4	171 (91)	83%
		> 3 months	–.77*	(–1.30 to–.25)	1	60 (30)	NA
	Participants' condition	Non-binge eaters	–.24	(–1.43 to .96)	2	56 (27)	79%
		Binge eaters	–1.28*	(–1.84 to –.71)	3	175 (94)	65%
	Follow-up distance	< 3 months	–1.33*	(–2.24 to –.38)	2	83 (40)	72%
		> 3 months	–.63	(–1.51 to .25)	3	148 (81)	83%
Change in PA level			.42*	(.15 to .69)	4	222 (112)	2%
Mindfulness skills			–.40*	(–.12 to –.67)	3	204 (100)	0%

CI: confidence interval. PA: physical activity. NA: not applicable.
* $p < .05$.

Table 4. Meta-regression analyses predicting outcomes with candidate moderators.

Outcome measure	Moderator variables	Estimate	*95% CI*	Heterogeneity accounted for moderators (R^2)	Residual heterogeneity (I^2)
Body Mass Index	Type of intervention	–.33	(–3.00 to 2.33)	100%	0%
	Focus of intervention	.74	(–1.71 to 3.19)		
	Intervention duration	–1.05	(–2.74 to .63)		
	Participants' condition	–.26	(–1.08 to .57)		
	Follow-up distance	1.18*	(.20 to 2.16)		
Impulsive eating	Focus of intervention	1.24	(–1.24 to 3.72)	18.34%	74.63%
	Participants' condition	.53	(–1.95 to 3.00)		
Binge eating	Type of intervention	.06	(–.80 to .91)	65.64%	53.07%
	Participants' condition	–.97*	(–1.86 to –.07)		

CI: confidence interval. Type of intervention: 0=non-behavioral, 1=behavioral. Focus of intervention: 0=eating behaviors, 1=weight loss. Intervention duration: 0=less than 3 months, 1=more than 3 months. Participants' condition: 0=non binge eaters, 1=binge eaters. Follow-up distance: 0=less than 3 months, 1=more than 3 months

* $p < .05$.

3.3.2.3. Change in physical activity.

Overall, there was a small-to-medium statistically significant between-group effect of mindfulness training on change in physical activity from baseline to post-intervention in RCTs in adults with overweight and obesity ($p < .01$) (see Table 3). Assessment of heterogeneity showed low and statistically non-significant levels of heterogeneity among the trials assessing physical activity at baseline and post-intervention ($p = .38$). No meta-regression analysis has been conducted for physical activity as levels of heterogeneity were considered low.

3.3.2.4. Mindfulness skills.

Overall, mindfulness skills at post-intervention were statistically significantly lower in the intervention groups than controls ($p < .01$) (see Table 3). Comparing mindfulness skills at baseline and post-intervention in the intervention groups, the overall effect of mindfulness training on mindfulness skills was not statistically significant ($d = –.05$; 95% CI –.66 to .55; $p = .86$). Assessment of heterogeneity showed statistically significant and substantial-to-high levels of heterogeneity among the trials ($p < .01$).

4. Discussion

The purpose of the current review was to conduct a quantitative synthesis of the effects of mindfulness-based training on BMI, health-related behaviors (impulsive eating, binge eating, physical activity), and mindfulness skills in a total of 12 RCTs with adults with overweight and obesity. The findings of our meta-analysis do not support the hypothesis that mindfulness training will have an effect on BMI measured between three days and three months post-intervention. However, our findings support the hypothesis that mindfulness training reduces impulsive and binge eating, and increases physical activity levels, in adults with overweight and obesity. More precisely, example results from included studies suggest that mindfulness training resulted in a mean reduction in binge episode frequencies from 18 episodes at baseline to five episodes at post-intervention over a 28 day period [61]. Moreover, example findings from included studies suggest a mean increase in energy expenditure (i.e., physical activity levels) resulting from mindfulness training from 767 kcal/week at baseline to 1700 kcal/week at post-intervention [58].

The results of the current analysis indicate that mindfulness training could be effective in reducing of impulsive and binge eating in individuals with overweight or obesity, as well as increasing levels of physical activity, which should lead to a better energy balance and contribute to better weight management [2]. These results for two key health-related behaviors are consistent with previous findings suggesting that higher mindfulness skills are associated with better self-perceptions of physical and mental health in clinical and non-clinical contexts [25]. Mindfulness is known to reduce impulsivity by acting as a de-automation component of self-regulation [34], and to reduce impulsive eating even when individuals are exposed to food cues by accepting the experience judged as frustrating [43]. In addition, mindfulness increases physical activity levels in adults with overweight and obesity, and previous findings suggest that bringing an open awareness to present experiences could foster the impact of intentions and motivations to adopt physical activity behaviors [46, 47], and could increase satisfaction to be physically active [49]. Thus, simply observing, non-judging, and accepting an aversive experience appears to lead to a more rational decision-making in the context of health behaviors. In fact, automatic thoughts, emotions, and behaviors seem to change while being mindful, even if the situation is perceived as aversive (e.g., taking the stairs at work instead of the elevator). There is a need for investigations testing the effectiveness of mindfulness training on behavior change in adults with overweight and obesity to include measures that would enable tests of mechanism through mediation. For example, researchers should consider introducing measures of the psychological factors

linked to behavior engagement (e.g., intentions and motivations to change) and cognitive processes (e.g., tendency to act impulsively when exposed to food cues) to better understand the role of mindfulness in weight management.

In contrast, our results suggested that RCTs investigating the effects of mindfulness training are not effective in reducing BMI in adults with overweight and obesity. This apparent discord in the findings relative to the findings for the behavioral outcomes may be due to a number of reasons. Weight loss outcomes require sustained behavior change both in terms of energy expenditure through physical activity and calorie restriction through dietary change. More studies with long-term follow-ups for weight loss and seeking change in both physical activity and eating behavior simultaneously may provide a better indication of the efficacy of these interventions on weight loss. Another possible influence is the measures used to tap physical activity. Participants could have overestimated their self-reported levels of physical activity, and, thus, adoption of objective measures of energy expenditure in future research would provide estimates of physical activity that were free of response bias [66]. A further explanation may lie in the primary focus of the interventions: nine trials focused exclusively on eating behavior and only three focused on weight loss as the primary outcome. Findings for BMI should be treated as preliminary given the considerable heterogeneity in the effect sizes and few trials measured weight-loss at follow-up more than 6 months post-intervention, and further investigations are needed. Our meta-regression analyses showed that (1) follow-up distance from post-intervention was the most predictive design characteristic for weight loss and (2) that differences in intervention type was fully responsible for high heterogeneity in the results. These results suggest that longer follow-up distances are associated with greater weight loss following mindfulness training. This tallies with our previous point that it takes time for behavioral changes to be manifested in changes in weight. It also indicates the need for researchers to adopt appropriate intervention type (i.e., behavioral instead of non-behavioral) to test the effects of mindfulness-based interventions.

Furthermore, only three trials assessed mindfulness skills at baseline and post-intervention, and, contrary to expectations, our findings suggest a decrease in mindfulness skills as a result of mindfulness training. Baseline scores of mindfulness skills in participants could explain the reverse effect of mindfulness training on mindfulness skills in the included trials. In fact, participants in both intervention and control groups appeared to report high levels of mindfulness skills prior to the beginning of the intervention. Meta-analytic evidence of the effectiveness of mindfulness training on mindfulness skills in clinical and non-clinical samples of participants revealed that training should increase skills [67]; making the results of the present meta-analysis suggest that individuals with excess weight may benefit most from mindfulness training. Moreover, the use of self-report measures of mindfulness skills has been questioned and strongly criticized in the literature [68] in so far as these measures do not report on actual skills developed in mindfulness training programs. Recent efforts from research teams showed that breath counting during meditation sessions was associated with higher mindfulness skills and could be considered in future investigations as a behavioral measure of mindfulness skills [69]. Furthermore, measures of effortless attention could also be included as a biomarker of mindfulness practice for experienced meditators [70].

In addition, selection bias was assessed as ‘high’ in the majority of the included studies. Methods for recruiting participants in psychological interventions need to be reviewed in studies on patients with overweight and obesity to limit the effects of prior motivation to participate in such interventions. Selection bias has been observed in many studies (e.g., Blevins 2009, Fletcher 2012) and presents a considerable challenge to research in health-related behavioral interventions that consistently relies on self-nomination of eligible individuals when it comes to recruitment to RCTs. Previous investigations of patients’ motivation to attend weight loss interventions showed that (1) even if referred by their general

practitioner, the majority of individuals with obesity are unlikely to schedule an appointment in a weight management clinic [71], and (2) patients' motivation to attend a treatment is the best predictor of weight loss and weight-loss maintenance following weight-loss interventions [72]. Systematic baseline assessment of prior intentions or motivation to participate in psychological interventions could be a strategy to control selection bias, as well as a potential moderator or mediator of the observed effect. Moreover, avoiding compensation for participation could also limit the effects of extrinsic motivation to enter psychological interventions. These two main biases could have affected adherence to interventions, which raises questions regarding the efficacy of mindfulness-based training in patients who did not self-select to participate in the trials. However, such biases exist in interventions that are administered to the community, outside the scope of a research study, so the potential confounding effect of selection bias in included studies may not affect the translation to clinical effectiveness of mindfulness training. Moreover, the majority of participants in studies included in this review were women. This finding is consistent with previous investigations showing that women tend to be more interested and motivated to engage in mindfulness-based interventions, and, as a consequence, they are more likely to respond to such treatment programs than men [44, 73].

The current analysis has several strengths. First, the adoption of meta-analytic techniques provides precise estimates of the effects of mindfulness training than systematic reviews that rely on 'vote-counts' of statistical significance of individual findings and do not statistically correct for methodological artifacts like sampling error. Second, the systematic literature search and strict selection criteria aimed to retrieve all relevant studies testing the effects of mindfulness training in individuals with overweight and obesity on weight loss, impulsive eating, binge eating, and physical activity levels. Moreover, the results of our meta-analysis are in accordance with previous reviews that aimed at investigating the effects of mindfulness- and acceptance-based interventions on obesity-related disordered eating and weight changes in individuals with overweight and obesity [37-40]. The choice to include measures of energy intake as well as energy expenditure was made to better understand the role of mindfulness in weight loss, arguing that mindfulness training could impact health-related behaviors leading to a reduction in BMI. Furthermore, we chose to include studies in that included all forms of mindfulness training, while previous reviews (except [40]) focused on separate conceptualizations of mindfulness- and acceptance-based interventions. In addition, meta-regression allowed us to identify the characteristics of included studies that might influence the size of intervention effect or its statistical heterogeneity. While non-behavioral mindfulness-based interventions (e.g., MB-EAT) showed no effect on binge eating [31, 56, 62], our analysis showed that behavioral interventions (e.g., ACT) seem to reduce binge eating [61, 64] (see Table 3).

A number of limitations of our analysis should be noted. First, we identified substantive between-study heterogeneity for many of the effects in the current analysis. The heterogeneity points to the likely presence of extraneous moderating variables likely influencing effect sizes. We specified numerous candidate moderating variables of mindfulness training effects including differences between mindfulness techniques and methodology, baseline characteristics of the participants, and intervention duration. We attempted to resolve heterogeneity across studies by conducting meta-regression analyses of the candidate moderators. Future meta-analyses in this field should conduct subgroup analyses based on these candidate moderators when sufficient effect sizes are available. Second, the likely presence of publication bias should be considered a limitation in the current review as we only considered published trials in our inclusion criteria. It must, however, be stressed that examination of the asymmetry in funnel plots did not indicate small-study bias, often interpreted as publication bias i.e. the tendency for studies with effect sizes disproportionate

to their sample size to get published. However, the high heterogeneity precluded a formal test of small-study bias using Egger's regression analyses, so we cannot unequivocally rule out the potential for the current effect size to be affected by publication bias. Finally, most of the studies included in the present analysis did not provide sufficient information on allocation concealment, blinding of participants and personnel, blinding of outcome assessment, and imputation of missing data. Future studies testing mindfulness training in individuals with overweight and obesity should report these important design and analytic procedures.

In conclusion, the present study suggests that mindfulness training shows promise in reducing impulsive eating and binge eating, and increasing physical activity levels among adults with overweight and obesity. Including individuals with poor mindfulness skills and impulsive and binge eaters in the trials would provide better evidence as to the effectiveness of mindfulness training among individuals with overweight and obesity who have these factors that may particularly predispose to having extreme difficulties when managing their weight. Future investigations in this field should focus on the role of mindfulness skills on eating outcomes as well as physical activity levels. A priority for future research is to provide better data on the long-term impact of mindfulness training on weight loss. Furthermore, adherence to the mindfulness training should be measured and clearly stated in future investigations.

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