REVIEW

Public Health / Behavior

Do eating behavior traits predict energy intake and body mass index? A systematic review and meta-analysis

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[Correction added on 18 November 2022, after first online publication: The order of author names have been corrected in this version.]

Summary

At present, it is unclear whether eating behavior traits (EBT) predict objectively measured short-term energy intake (EI) and longer-term energy balance as estimated by body mass index (BMI). This systematic review examined the impact of EBT on BMI and laboratory-based measures of EI in adults ($\geq$ 18 years) in any BMI category, excluding self-report measures of EI. Articles were searched up until 28th October 2021 using MEDLINE, PsycINFO, EMBASE and Web of Science. Sixteen EBT were identified and the association between 10 EBT, EI and BMI were assessed using a random-effects meta-analysis. Other EBT outcomes were synthesized qualitatively. Risk of bias was assessed with the mixed methods appraisal tool. A total of 83 studies were included (mean BMI = 25.20 kg/m^2, mean age = 27 years and mean sample size = 70). Study quality was rated moderately high overall, with some concerns in sampling strategy and statistical analyses. Susceptibility to hunger ($n = 6$) and binge eating ($n = 7$) were the strongest predictors of EI. Disinhibition ($n = 8$) was the strongest predictor of BMI. Overall, EBT may be useful as phenotypic markers of susceptibility to overconsume or develop obesity (PROSPERO: CRD42021288694).

KEYWORDS
eating behavior, energy intake, obesity

1 | INTRODUCTION

Obesity is a common, serious, and costly condition with significant health care and societal costs.[1] There is current interest in identifying psychological and physiological markers that characterize individuals who are susceptible to weight gain. Eating behaviors influence amount and types of foods eaten and hence energy intake (EI).[2] Eating behavior traits (EBT) are considered to be reliable, acquired indices of food-related behaviors.[3] EBT have been extensively studied in an attempt to identify potential markers that detect tendency to over-consume.[4] This has led to the development of several constructs and psychometric measures, which aim to capture important individual differences in eating behavior and disordered eating symptomology, for example, the Three Factor Eating Questionnaire (TFEQ) with sub-scales for cognitive restraint, susceptibility to hunger and disinhibi-tion.[5] Many EBT have been reported to be associated with excess food intake.[6-9] However, 'overconsumption' is often assessed by other self-report measures which are prone to misreporting and not truly representative of actual food intake.[10] For example, in a system-atic review on the associations between emotions and eating behav-ior, the majority of studies associated self-reported emotions with another self-reported EBT as a proxy of food intake.[11] Associations

between EBT and EI have yet to be extensively reviewed and little is known about which EBTs influence objectively measured EI.

Previous systematic reviews have begun to answer these questions indirectly by examining associations between EBT and BMI.[9,11,12] BMI is an index of long-term energy balance status. Vainik, Dagher, Dubé and Fellows[12] found that several different personality measures were consistently associated with BMI. However, very few measures included were eating-related. French, Epstein, Jeffery, Blundell and Wardle[9] reviewed seven eating behavior dimensions and found that most of the available data showed positive cross-sectional associations with BMI. However, very few studies reported measures of EI and only four measures were eating-related. Overall, disinhibition had the largest empirical support to link it prospectively with weight gain and a narrative review also found that disinhibition plays a significant role in obesity, diet quality and uncontrolled eating patterns.[13] As few measures associated with psychological eating behavior have been reviewed, this systematic review aimed to assess all possible psychological EBT.

EBT are theoretical constructs operationalized through eating-related measures. There is currently no database of EBT, and studies often refer to these traits with different names, for example, overeating measures, eating behavior dimensions, appetite measures and eating attitudes. Consequently, a conceptual diagram was developed to capture the scales used to assess EBT and to a-priori allocate all of the collected scales to theoretical domains (see Figure 1). Firstly, a scoping exercise was conducted to create EBT domains, then subdomains were identified, which formed the basis for the search strategy.

Secondly, this systematic review was conducted to identify studies that included measures of both EI and BMI in the same population. This systematic review included only laboratory-based measures of EI. Use of a controlled environment allows for more standardized, objective measurement of EI.[14] This is more accurate and precise than self-report EI.[15]

The primary aim of this systematic review was to examine whether EBT predicts short-term EI and whether there is evidence that this effect translates into longer term energy balance, as estimated by BMI. The specific research questions of the review were: (1) What measures are used to capture EBT? (2) How well do these measures predict short term EI? (3) How well do these measures predict BMI? (4) Do some EBT and questionnaires used to measure EBT better predict EI or BMI than others?

2 | METHODS

2.1 | Information sources and search strategy

Four electronic databases were searched: MEDLINE (Ovid), PsycINFO (Ovid), EMBASE (Ovid) and Web of Science (core collection). The MEDLINE, Embase and PsychInfo strategies were run simultaneously as a multi-file search in Ovid on 28th October 2021. Searches for all databases are included in Table S1. The conceptual diagram, alongside the identification of key databases formed the basis for the search strategy (see Figure 1). All proposed EBT and their domains were
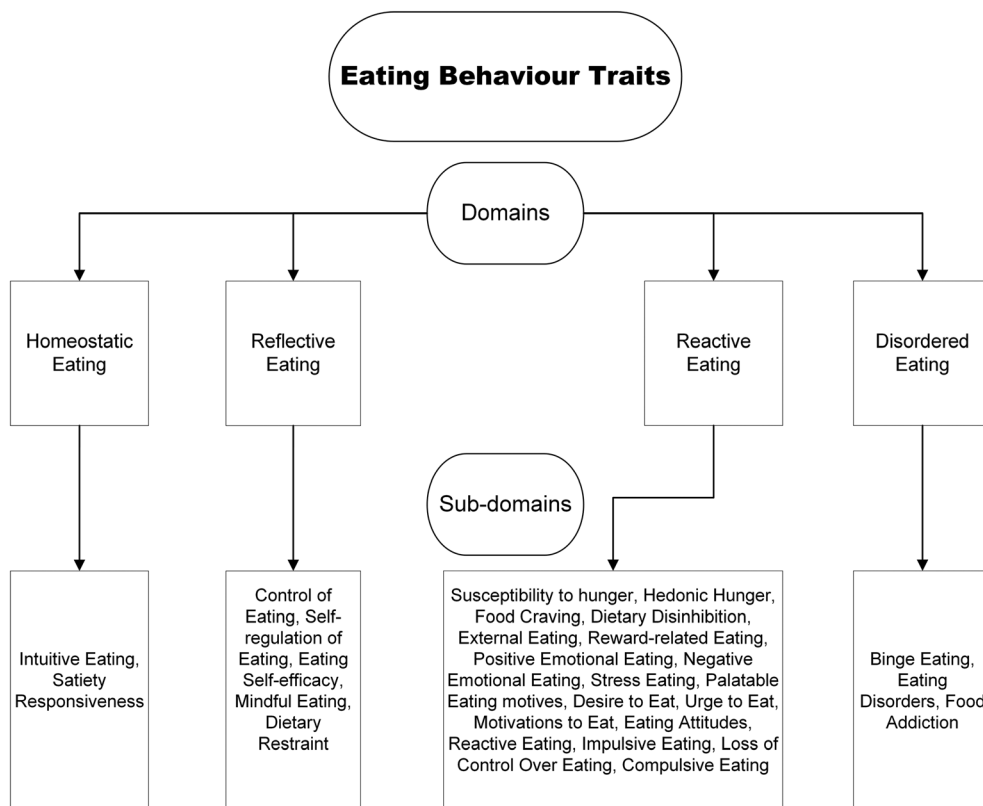

FIGURE 1 A conceptual diagram of eating behavior traits.

included in the search. Key databases such as the UCL database for eating behavior questionnaires,[16] NIH obesity measures,[17] and Arab psychology scales[18] were used to find relevant eating-related questionnaires to include in the search. Because many studies use EBT but not in relation to measured eating behavior, the search also required studies to include key words related to eating behavior or eating traits (see Table S1). The two outcome measures were EI and BMI (and their related terms, see Table S1). Limits were set to include articles published in English (as translating studies into English could lead to relevant information being mistranslated) and humans. The search strategies were peer reviewed by three experts in the field (KB, JS, GF) prior to execution using the PRESS checklist.[19] Duplicates were removed using Screenatron's 'deduplication' tool and were checked to ensure all duplicates found were actual duplications. This systematic review followed PRISMA guidelines[20] and was pre-registered with PROSPERO (registration number = CRD42021288694).

2.2 | Study selection, inclusion, and exclusion

Articles were included if they recruited adults (≥18 years including older adults) in any BMI category. The presence of the following was not excluded: type 2 diabetes, pre-menopausal/post-menopausal women, cardiovascular diseases. Those with the following comorbidities were excluded: Parkinson's disease, anorexia, bulimia nervosa, binge eating disorder, cancers, inflammatory bowel diseases, intellectual deficiency, psychiatric conditions, sleep disorders, those having undergone weight loss surgery (gastric bypass or bariatric surgery) and those who were pregnant. As binge eating was identified as an EBT in the scoping exercise, any study that used a binge eating scale (e.g., binge eating scale[21]) to classify binge eaters was included. However, if studies identified participants with binge eating disorder using a version of the DSM, for example, DSM-5,[22] this was not recognized as an EBT and these studies were excluded. Studies that measured psychological variables, for example, stress or mood, were excluded unless an EBT was also measured, for example, emotional eating. In cases where studies measured other variables alongside EBT, the reviewers discussed whether these variables would be considered potential contaminates of the outcomes. For example, an alcohol preload or a food craving protocol were considered potential contaminates and were excluded if no data was given for a control condition. Self-report measures of EI were excluded as this systematic review focused on laboratory-based measures of EI but were saved for a future review. Laboratory-based measures of EI also included studies where EI was measured in a laboratory and weighed food was given to participants to take home and bring back to be re-weighed, as this measure of EI is considered in the literature to be ad-libitum EI.

All titles and abstracts were assessed for eligibility by the main author (CD) and were also independently screened by three researchers (MH, JS, GF), with uncertainty regarding eligibility discussed among the researchers. Reference lists from the resulting reviews were also screened to identify additional articles. Full texts were retrieved and assessed for eligibility by CD and were also independently assessed by JS and GF. Intervention studies that included results for a control condition or baseline measures were included. Studies that only measured one of the outcomes variables (EI or BMI) were excluded. If a study measured both outcome variables but the results for one of the outcome measures was missing, the study authors were contacted for the missing outcome results. In this case, the study was included for data extraction as both outcome variables were measured. Thirty-three authors were contacted about missing data. Five authors responded with the necessary data.

2.3 | Data extraction and synthesis

Data was extracted by one author (CD) and was cross-checked for data extraction errors by JS and GF. Data was extracted using the data collection form for intervention reviews (randomized control trials and non-randomized control trials) from the Cochrane group.[23] The characteristics of each included article consisted of title, study ID, publication type, study design, aim of the study, ethical information, number of participants, population characteristics (age, BMI, % female, ethnicity, population description, method of recruitment, inclusion/exclusion criteria), description of EBT, description of outcomes (method, definition, unit of measurement and validation information for the collection and measurement of BMI and EI), study funding sources, possible conflicts of interests, data and analysis (results, including number of participants, means and standard deviations where possible, unit of analysis, statistical methods used and appropriateness of these), key conclusions of study authors and references to other available studies. Where means and standard deviations were not reported, correlations, F-values or t-values were extracted, and standard errors were converted to standard deviations. Effects on EI and BMI were examined using a random-effects meta-analysis because it was anticipated that there would be considerable between-study heterogeneity. All analyses were carried out in the R environment, version 2021.09.0.[24] The following R packages were used: dmetar,[25] esc,[26] tidyverse,[27] and meta.[28]

Meta-analysis of the effect of each EBT on BMI and EI was performed when ≥2 effect sizes were available for each trait. For each analysis, effect sizes were pooled using the r value from correlations and were transformed to Fisher's Z.[29] Where correlations were not present, the available raw data were transformed into Fisher's Z. Where one study provided data for more than one questionnaire (e.g., all participants completed the DEBQ and TFEQ), the sample size was halved to prevent 'double counting', which can artificially inflate effect sizes and distort results.[30,31] If studies provided data for multiple types of EI outcome, for example, sweet, and savory EI, or provided data for multiple preloads, the selected outcomes were pooled to provide a single 'total EI' correlation, to prevent overpowering of a single study. Effect sizes based on Fisher's Z were interpreted as very small (≤0.05), small (>0.05–<0.10), moderate (>0.10–<0.30), large (>0.30–<0.40), and very large (≥0.40).[32] The restricted maximum likelihood estimator was used to calculate heterogeneity variance and heterogeneity was also evaluated using the I-squared

statistic (I^2), with values inferred as low (<25%), moderate (25%–75%), and high (>75%). However, the I^2 statistic was interpreted cautiously when the number of studies in each meta-analysis was <7. In this case, it is advised that confidence intervals should supplement the I^2 statistic; therefore, confidence intervals were also provided for each meta-analysis.[33] Knapp-Hartung adjustments[34] were also used to calculate the confidence interval around the pooled effect. The Knapp-Hartung adjustment can reduce the chance of false positives, especially when the number of studies is small.[35] The results of the meta-analyses are presented as forest plots, which include the authors, standard error (SE), questionnaire type, correlation (COR), 95% confidence intervals, weight and Hedges G[36] that is converted from Fisher's Z.

Further analysis of outliers and influential cases was conducted using a leave-one-out analysis in addition to identifying influential cases, and results are reported for both the main meta-analyses and further analyses where outliers or influential cases were removed. Publication bias was assessed by visually inspecting the funnel plot and Egger's regression test when the number of included studies was <10. Duval and Tweedie's trim-and-fill method was also used. Two subgroup analyses were conducted to test whether the effect of restraint on BMI and EI was influenced by the type of questionnaire used because the questionnaires used to measure restraint varied across studies. Additionally, a subgroup analysis tested whether the use of a preload influenced the correlation between restraint and EI. Studies were split into 'no preload' and 'preload' categories. For the preload studies, effect sizes were conducted for both no preload and preload groups, and sample size was halved to prevent double counting.[30,31] Where studies included multiple preload conditions, the largest preload condition was used to calculate the effect size. Subgroup analyses were also conducted to test the influence of meal type (1 test meal vs. multiple test meals) where there were ≥10 effect sizes available for each EBT and ≥2 per category.

2.4 | Quality assessment

To assess risk of bias, the excel version of the mixed method appraisal tool (MMAT) for appraising studies was used.[37] It is a critical appraisal tool designed for systematic mixed studies reviews (including qualitative, quantitative, and mixed methods studies). The MMAT has been pilot tested and has high content validity.[38] The following questions were answered to determine the risk of bias: is the sampling strategy relevant to address the research question, is the sample representative of the target population, are the measurements appropriate, is the risk of nonresponse bias low and is the statistical analysis appropriate to answer the research question? The four assessment items represented flaws if answered "No/cannot tell." It is discouraged to calculate an overall score from the ratings of each criterion; therefore, a detailed discussion of the ratings follows. Quality assessment was completed by the main reviewer (CD) and was cross-checked by JS and GF.

3 | RESULTS

2,760 articles were retrieved from the four databases. After deduplication, 1955 articles remained for title and abstract screening. The reasons for excluding any studies that did not meet the inclusion criteria during full text screening are shown in the flow diagram in Figure 2. Seventy-seven papers met the inclusion criteria and were included in this systematic review, with some papers consisting of several studies. In total, 83 studies were included. Several studies could not be synthesized for each EBT meta-analysis; therefore, the number of studies included in each meta-analysis varies. Where meta-analysis was not possible, associations between the EBT and outcome variables are qualitatively summarized. Table 1 gives the included questionnaires used to measure EBT and their abbreviations.

3.1 | Study characteristics

Study characteristics are summarized in Table 2 (see Table S2 for more detailed characteristics). The studies were published between 1975 and 2021. All data from the studies are cross-sectional. The following EBT were identified, restraint ($n = 50$), disinhibition ($n = 17$), emotional eating ($n = 12$), binge eating ($n = 8$), external eating ($n = 7$), susceptibility to hunger ($n = 6$), hedonic hunger ($n = 4$), satiety responsiveness ($n = 3$ via Satiety Quotient, SQ) and $n = 1$ via AEBQ), intuitive eating ($n = 3$), food craving ($n = 1$), mindful eating ($n = 1$), eating disorders ($n = 1$), food addiction ($n = 1$), eating self-efficacy ($n = 1$), control of eating ($n = 1$), reward-related eating ($n = 1$). The mean (range) of the total sample size was 70 (18–273). The mean (range) age of participants was 27 years (19–59 years); BMI was 25.20 kg/m^2 (21.0–36.8 kg/m^2). Males and females were included in 25 studies, females only in 56 studies, males only in 1 study and no data was given for 1 study. BMI was objectively measured in 52 studies, self-reported in 10 studies, and in 21 studies, there was no information for how BMI was measured. Measures of EI varied widely across studies. EI was measured over one test meal in 69 studies and across multiple test meals in 14 studies. Studies also used various types of food to measure EI. Overall, snack foods were the most popular EI measure ($n = 29$). Multiple food items ($n = 21$), pasta ($n = 8$), cookies ($n = 5$), ice cream ($n = 5$), popcorn ($n = 3$), sandwiches ($n = 3$), vending machines ($n = 2$), beef casserole ($n = 2$), risotto ($n = 1$), pizza ($n = 1$), milkshake ($n = 1$), Boost (a nutritionally complete liquid supplement, $n = 1$) and breakfast foods ($n = 1$) were also used.

3.2 | Study quality

Overall, studies scored relatively high on study quality for four out of five quality criteria. Studies scored low for sampling strategies because none used probability sampling and most recruited via opportunity sampling. Studies did define their target population by presenting inclusion and exclusion criteria, and some included a-priori sample size calculations. Respondents and the target population were well
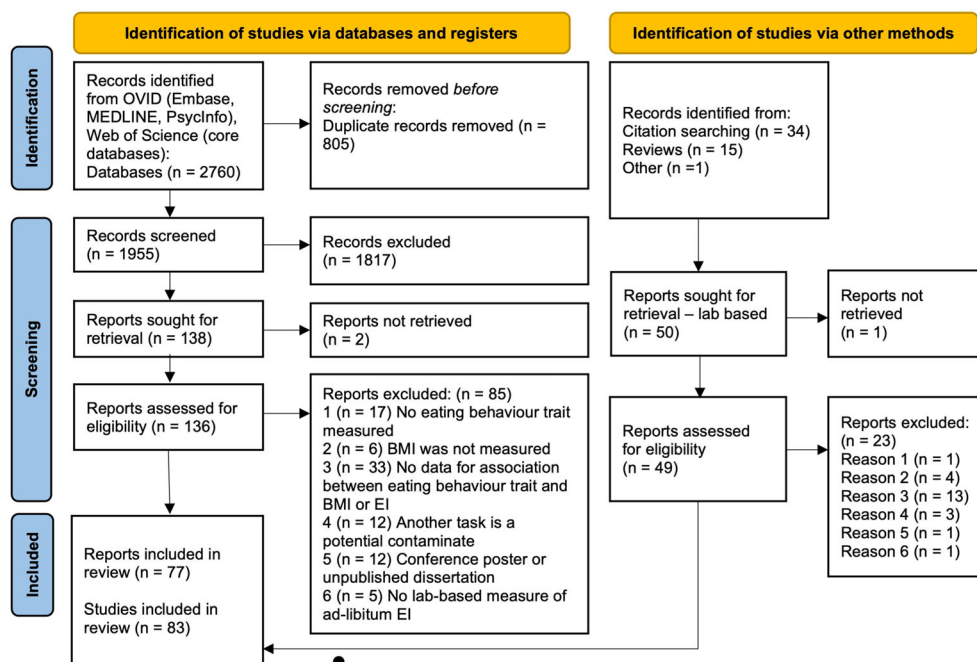
matched and the reasons why certain individuals were excluded were made clear. All questionnaires have been validated and in 51 studies, BMI was measured objectively in the laboratory. The measurements of EI were, for most studies, not previously validated and the most frequently used type of food was snacks ($n = 28$). The extent to which findings of eating behavior, using energy dense snacks can generalize to wider and more typical eating behavior is unknown. The majority of studies also attempted to reduce possible confounders by providing participants with a standardized breakfast, testing during normal lunch hours and keeping testing times between participants consistent.

The risk of non-response bias in studies included in this systematic review was low, no studies reported high drop-out rates. Lastly, study quality was high for the appropriateness of statistical analysis used in studies. However, in some studies, the method used to split participants into groups was a limitation. Using a median split to identify low or high scorers could have misclassified individuals and lead to null findings.[11] Indeed, van Strien, Herman, Anschutz, Engels and de Weerth[119] found that if a median split was used, their results would have become non-significant. Additionally, in Dalton, Hollingworth, Blundell and Finlayson,[60] 40% of the participants were unclassified based on their SQ score. Therefore, any findings cannot be generalized to a wider population if almost half of the sample could not be classified into a level of satiety responsiveness.

3.3 | Study findings

3.3.1 | Intuitive eating

A meta-analysis of 2 studies ($n = 262$) found no significant correlation between intuitive eating and EI ($r = 0.32$ [-0.30, 2.00],

$p = 0.096$). A meta-analysis of 3 studies ($n = 317$) found that intuitive eating was negatively correlated with BMI ($r = -0.26$ [-0.45, -0.04], $p = 0.036$, Figure S1) and this represents a moderate effect size. Heterogeneity was low ($I^2 = 0.0\%$, $Q = 1.66$, $p = 0.436$). One study was identified as an influential case.[57] With this study removed from the meta-analysis, the overall effect size increased; however, the effect became non-significant ($r = -0.30$ [-0.86, 0.58], $p = 0.156$). The trim-and-fill method suggested no missing studies.

3.3.2 | Mindful eating

Anderson, Reilly, Schaumberg, Dmochowski and Anderson[58] found no significant association between mindful eating and EI ($r = 0.15$) or mindful eating and BMI ($r = 0.01$).

3.3.3 | Satiety responsiveness

Only one effect size was available; therefore, meta-analysis could not be conducted. However, of the four studies that measured satiety responsiveness, three reported that higher satiety responsiveness as associated with reduced EI[60,62,63] and one reported no significant effect.[62] A meta-analysis of 3 studies ($n = 197$) found a moderate negative correlation between satiety responsiveness and BMI ($r = -0.18$ [-0.31, -0.04], $p = 0.031$, Figure S2). Heterogeneity was low ($I^2 = 0.0\%$, $Q = 0.41$, $p = 0.815$). No studies were identified as outliers or influential cases. Two missing studies were suggested to the right (adjusted $r = -0.15$ [-0.24, -0.06], $p = 0.009$).

TABLE 1 Table of questionnaires included and their abbreviations

Questionnaire	Abbreviation	Subscales	Reference paper
Intuitive Eating Scale	IES	Reliance On Hunger and Satiety (RHSC), Unlimited Permission to Eat (UPE), Eating for Physical Rather Than Emotional Reasons (EPR)	Tylka[39]
Intuitive Eating Scale-2	IES-2	RHSC, UPE, EPR, Body-Food Choice Congruence (B-FCC)	Tylka and Kroon Van Diest[40]
Mindful Eating Questionnaire	MEQ	Disinhibition, Awareness, External Cues, Emotional Response, Distraction	Framson, Kristal, Schenk, Littman, Zeliadt and Benitez[41]
Satiety Quotient	SQ	Desire To Eat, Hunger, Fullness, Satiety, Prospective Food Consumption (PFC)	Green, Delargy, Joanes and Blundell[42]
Adult Eating Behavior Questionnaire	AEBQ	Hunger (H), Food Responsiveness (FR), Emotional Over-Eating (EOE), Enjoyment of Food (EF), Satiety Responsiveness (SR), Emotional Under-Eating (EUE), Food Fussiness (FF), Slowness in Eating (SE)	Hunot, Fildes, Croker, Llewellyn, Wardle and Beeken[43]
Three Factor Eating Questionnaire	TFEQ	Disinhibition, Dietary Restraint, Susceptibility to Hunger	Stunkard and Messick[5]
Restraint Scale	RS		Herman and Mack[44]
Revised Restraint Scale	RRS		Herman, Polivy and Silver[45]
Dutch Eating Behavior Questionnaire	DEBQ	Restraint Eating, Emotional Eating, External Eating	van Strien, Frijters, Bergers and Defares[46]
Control of Eating Questionnaire	COEQ	Craving Control, Positive Mood, Craving for Sweet, Craving for Savory	Dalton, Finlayson, Blundell and Hill[47]
Power of Food Scale	PFS	Food Available, Food Present, Food Tasted	Lowe, Butryn, Didie, Annunziato, Thomas, Crerand, Ochner, Coletta, Bellace and Wallaert[48]
Food Craving Inventory	FCI	High fats, Sweets, Carbohydrates, Fast-Food Fats and Subjective, Behavioral	White, Whisenhunt, Williamson, Greenway and Netemeyer[49]
Binge Eating Scale	BES		Gormally, Black, Daston and Rardin[21]
Eating Disorders Examination Questionnaire	EDE-Q	Restraint, Eating Concern, Shape Concern, Weight Concern	Fairburn, Cooper and O'Connor[50]
Eating Disorders Assessment Scale	EDAS	Restrained Eating, Binge Eating, Purging, Preoccupation with Body Image, and Body Weight.	Akkermann, Herik, Aluoja and Järv[51]
Eating Disorders Diagnostics Scale	EDDS	Anorexia Nervosa, Bulimia Nervosa, Binge Eating Disorder, Noneating Disordered	Stice, Telch and Rizvi[52]
Eating Disorders Inventory	EDI-2	EBT related subscales: Drive for Thinness, Bulimia, Body Dissatisfaction	Garner[53]
Eating Self-Efficacy	WEL	Negative Emotions, Availability, Social Pressure, Physical Discomfort, Positive Activities	Clark, Abrams, Niaura, Eaton and Rossi[54]
Reward-based Eating Drive Questionnaire	RED-9, RED-13, RED-X5	Loss of Control Over Eating, Lack of Satiety, Preoccupation with Food	Vainik, Eun Han, Epel, Janet Tomiyama, Dagher and Mason[55]
Yale Food Addiction Scale-2	YFAS-2		Gearhardt, Corbin and Brownell[56]

3.3.4 | Restraint

Meta-analysis of 49 studies ($n = 2,594$) showed a small but significant, negative correlation between restraint and EI (52 study arms, $r = -0.07$, [-0.12, -0.01], $p = 0.015$, Figure 3). Heterogeneity was moderate ($I^2 = 41.8\%$, $Q = 87.70$, $p = 0.001$). Four outliers were identified[68,74,78,79] and the one-study-removed procedure identified

one influential case.[74] With these outliers removed, the effect size slightly increased ($r = -0.09$ [-0.14, -0.05], $p < 0.001$). Heterogeneity was low ($I^2 = 10.2\%$) and the Q test was non-significant ($Q = 52.32$, $p = 0.275$). The funnel plot did not suggest any evidence of publication bias (Figure S3), no missing studies were suggested, and Egger's test was non-significant ($p = 0.680$). The association between restraint and EI was influenced by the type of questionnaire used to

TABLE 2 Eating behavior traits: Summary of included studies

Eating behavior trait	Questionnaire used to assess eating behavior trait	Cross-sectional study reference	Associations with	
			EI	BMI
Intuitive eating (IE)	IES	Anderson, Schaumberg, Anderson and Reilly[57]	NS and ↑	↓
	IES	Anderson, Reilly, Schaumberg, Dmochowski and Anderson[58]	NS	NS
	IES-2	Ruzanska and Warschburger[59]	NS and ↑	↓
		Total	3 NS 2 ↑	1 NS 2 ↓
Mindful eating	MEQ	Anderson, Reilly, Schaumberg, Dmochowski and Anderson[58]	NS	NS
		Total	1 NS	1 NS
Satiety Responsiveness	SQ	Dalton, Hollingworth, Blundell and Finlayson[60]	↓	NS
	SQ desire to eat	Drapeau, Blundell, Therrien, Lawton, Richard and Tremblay[61]	NS	NS
	SQ for PFC		NS	NS
	SQ for fullness		↓	NS
	SQ for hunger		NS	NS
	SQ	Drapeau, Jacob, Panahi and Tremblay[62]	NS	NS
	AEBQ	Zuraikat, Roe, Smethers, Reihart and Rolls[63]	↓	NS*
		Total	4 NS 3 ↓	7 NS
Dietary restraint	TFEQ	Anderson, Reilly, Schaumberg, Dmochowski and Anderson[58]	NS	↑
	TFEQ	Ard, Desmond, Allison and Conway[64]	↓	
	TFEQ	Bellisle, Dalix, Airinei, Hercberg and Péneau[65]	NS	NS
	TFEQ	Bryant, Caudwell, Blundell, Hopkins and King[66]	NS	
	TFEQ	Chambers and Yeomans[67]	NS	NS
	RS	Coelho, Polivy, Herman and Pliner[68]	↑	↑
	RRS	Cools, Schotte and McNally[69]	↓	
	RS	de Witt Huberts, Evers and de Ridder[70] study 1	NS	↑
	RS	de Witt Huberts, Evers and de Ridder[70] study 2	NS	↑
	RS	de Witt Huberts, Evers and de Ridder[70] study 3	NS	NS
	DEBQ	Dweck, Jenkins and Nolan[71]		↑
	RRS	Fedoroff, Polivy and Herman[72]	↓	
	TFEQ	Finlayson, Blundell, Bordes, Griffioen-Roose and de Graaf[73]	NS	NS
	DEBQ	Finlayson et al.[73]	NS and ↑	
	RS	Guerrieri, Nederkoorn, Schrooten, Martijn and Jansen[74]	↑	↑
	TFEQ	Haynes, Lee and Yeomans[75]	↓	NS
	DEBQ	Herhaus and Petrowski[76]	NS	NS
	RS	Herman and Mack[44]	↑ and ↓	NS
	RS	Herman, Polivy and Silver[45]	↑	
	DEBQ	Higgs, Williamson and Attwood[77]	NS	NS
	TFEQ	Hofmann and Friese[78]	↓	
	DEBQ	Hopkins et al.[113]	↓	NS
	DEBQ	Jansen[79] study 1	↑	NS
		Jansen[79] study 2	↑	↑
	RS	Jansen, Merckelbach, Oosterlaan, Tuiten and Van Den Hout[80]	NS	↑

TABLE 2   (Continued)

Eating behavior trait	Questionnaire used to assess eating behavior trait	Cross-sectional study reference	Associations with EI	BMI
	RS	Lattimore and Maxwell[81]	NS	
	TFEQ	Martin, Williamson, Geiselman, Walden, Smeets, Morales and Redmann Jr[82]	NS	NS
	TFEQ	McNeil, Lamothe, Cameron, Riou, Cadieux, Lafreniere, Goldfield, Willbond, Prud'homme and Doucet[83]	NS	
	RRS	Myhre, Buchwald, Kratz, Goldberg, Polivy, Melhorn, Schur and Cummings[84]	NS	NS
	DEBQ	Oliver, Wardle and Gibson[85]	NS	
	DEBQ	Ouwens, van Strien and van der Staak[86]	NS	
	TFEQ	Ouwens, van Strien and van der Staak[86]	NS	
	RS	Ouwens, van Strien and van der Staak[86]	NS	
	TFEQ	Peluso[87]	NS	NS
	TFEQ	Rideout, McLean and Barr[88]	↓	NS
	DEBQ	Robinson and Haynes[115]	NS	NS
	TFEQ	Rolls, Castellanos, Shide, Miller, Pelkman, Thorwart and Peters[89]	NS	NS
	TFEQ	Ruddock, Field and Hardman[90]	↓	NS
	TFEQ	Schoch and Raynor[91]	↓	↑
	RRS	Schotte, Cools and McNally[92]	NS	↑
	RS	Shapiro and Anderson[93]	NS	
	DEBQ	Sim, Lee and Cheon[94]	NS	
	TFEQ	Smith, Geiselman, Williamson, Champagne, Bray and Ryan[95]	NS	↑
	RS and TFEQ	Stice, Fisher and Lowe[96] study 1	NS	NS
	TFEQ and EDEQ-R	Stice, Fisher and Lowe[96] study 2	NS	
	TFEQ	Stice, Sysko, Roberto and Allison[97]	NS	
	TFEQ	Stinson, Votruba, Venti, Krakoff, Gluck and Perez[98]	↓	NS
	DEBQ	van Strien and Ouwens[99]	NS	
	TFEQ	Visona and George[100]	NS	NS
	DEBQ	Wallis and Hetherington[101]	NS	NS
	DEBQ	Wallis and Hetherington[102]	↓	↑
	DEBQ	Wardle and Beales[103]	↑	NS
	TFEQ	Westenhoefer, Broeckmann, Münch and Pudel[104]	NS	↑
	RRS	Westenhoefer, Broeckmann, Münch and Pudel[104]	↑	↑
	TFEQ	Yeomans and Coughlan[105]	NS	NS
	TFEQ	Yeomans, Tovey, Tinley and Haynes[106]		NS
	TFEQ	Zambrowicz, Schebendach, Sysko, Mayer, Walsh and Steinglass[107]	↓	
	EDE-2	Zambrowicz, Schebendach, Sysko, Mayer, Walsh and Steinglass[107]	NS	
		Total	36 NS 9 ↑ 13 ↓	24 NS 14 ↑

TABLE 2 (Continued)

Eating behavior trait	Questionnaire used to assess eating behavior trait	Cross-sectional study reference	Associations with EI	BMI
Control of eating	COEQ Craving control Positive mood Lack of Craving for sweet[a]	Dalton, Finlayson, Blundell and Hill[47]	↓ ↓ ↓	↓ ↓ ↓
		Total	3 ↓	3 ↓
Hedonic hunger/food reward sensitivity	PFS	Appelhans, Liebman, Woolf, Pagoto, Schneider and Whited[108]	NS	NS
	PFS	Ely, Howard and Lowe[109]	NS and ↑	↑
	PFS	Finlayson et al.[73]	NS	NS
	PFS	Nolan-Poupart, Veldhuizen, Geha and Small[110]	NS	
		Total	4 NS 1 ↑	2 NS 1 ↑
Food craving	FCI	Martin, O'Neil, Tollefson, Greenway and White[111]	↑	
		Total	1 ↑	
Dietary disinhibition	TFEQ	Ard, Desmond, Allison and Conway[64]	NS	
	TFEQ	Bryant, Caudwell, Blundell, Hopkins and King[66]	NS	
	TFEQ	Chambers and Yeomans[67]	NS and ↑	
	TFEQ	Epstein, Lin, Carr and Fletcher[112]	↑	↑
	TFEQ	Finlayson, Blundell, Bordes, Griffioen-Roose and de Graaf[73]	NS and ↑	↑
	TFEQ	Haynes, Lee and Yeomans[75]	↑	NS
	TFEQ	Higgs, Williamson and Attwood[77]	NS	NS
	TFEQ	Martin, Williamson, Geiselman, Walden, Smeets, Morales and Redmann Jr[82]		NS
	TFEQ	McNeil, Lamothe, Cameron, Riou, Cadieux, Lafreniere, Goldfield, Willbond, Prud'homme and Doucet[83]	NS	
	DEBQ	Ouwens, van Strien and van der Staak[86]	↑	
	TFEQ	Ouwens, van Strien and van der Staak[86]	↑	
	TFEQ	Ruddock, Field and Hardman[90]	↑	NS
	TFEQ	Smith, Geiselman, Williamson, Champagne, Bray and Ryan[95]	↑	↑
	TFEQ	Stinson, Votruba, Venti, Krakoff, Gluck and Perez[98]	NS	↑
	TFEQ	Westenhoefer, Broeckmann, Münch and Pudel[104]	↑	↑
	TFEQ	Yeomans and Coughlan[105]	NS	↑
	TFEQ	Yeomans, Tovey, Tinley and Haynes[106]	↑	↑
	TFEQ	Zambrowicz, Schebendach, Sysko, Mayer, Walsh and Steinglass[107]	NS	
		Total	9 NS 10 ↑	4 NS 7 ↑
Susceptibility to Hunger	TFEQ	Bryant, Caudwell, Blundell, Hopkins and King[66]	↑	
	TFEQ	Finlayson, Blundell, Bordes, Griffioen-Roose and de Graaf[73]	NS	NS
	TFEQ	McNeil, Lamothe, Cameron, Riou, Cadieux, Lafreniere, Goldfield, Willbond, Prud'homme and Doucet[83]	↑	
	TFEQ	Stinson, Votruba, Venti, Krakoff, Gluck and Perez[98]	NS	↑
	TFEQ	Westenhoefer, Broeckmann, Münch and Pudel[104]	↑	↑

(Continues)

TABLE 2 (Continued)

Eating behavior trait	Questionnaire used to assess eating behavior trait	Cross-sectional study reference	Associations with EI	BMI
	TFEQ	Zambrowicz, Schebendach, Sysko, Mayer, Walsh and Steinglass[107]	NS	
		Total	3 NS 3 ↑	1 NS 2 ↑
External eating	DEBQ	Dweck, Jenkins and Nolan[71]		NS
	DEBQ	Finlayson et al.[73]	↑	NS
	DEBQ	Hopkins, Michalowska, Whybrow, Horgan and Stubbs[113]	NS	NS
	DEBQ	Kakoschke, Kemps and Tiggemann[114]	↑	
	DEBQ	Robinson and Haynes[115]	NS	NS
	DEBQ	van Strien, Donker and Ouwens[116]	↑	
	DEBQ	van Strien and Ouwens[99]	NS	
		Total	3 NS 3 ↑	4 NS
Emotional eating	DEBQ	Dweck, Jenkins and Nolan[71]	NS	NS
	DEBQ	Evers, de Ridder and Adriaanse[117] study 3	NS	NS
	DEBQ	Evers, de Ridder and Adriaanse[117] study 4	NS	NS
	DEBQ	Evers, de Ridder and Adriaanse[117] study 5	NS	NS
	DEBQ	Finlayson et al.[73]	NS and ↑	↑
	DEBQ	Hopkins, Michalowska, Whybrow, Horgan and Stubbs[113]	NS	NS
	DEBQ	Oliver, Wardle and Gibson[85]	NS	
	DEBQ	Raspopow, Abizaid, Matheson and Anisman[118]	NS	NS*
	DEBQ	Robinson and Haynes[115]	NS	NS
	DEBQ	van Strien, Donker and Ouwens[116]	↑	
	DEBQ	van Strien, Herman, Anschutz, Engels and de Weerth[119]		↑
	DEBQ	van Strien and Ouwens[99]	↑	
	DEBQ	Wallis and Hetherington[101]	NS	NS
	DEBQ	Wallis and Hetherington[102]		NS
		Total	10 NS 3 ↑	9 NS 2 ↑
Binge eating	BES	Alger, Seagle and Ravussin[120]		
	EDAS	Arumae, Kreegipuu and Vainik[121]	↑	NS
	BES	Dalton, Blundell and Finlayson[122]	↑	NS*
	BES	Dalton, Blundell and Finlayson[123]	↑	NS*
	BES	Finlayson, Arlotti, Dalton, King and Blundell[4]	↑	↑
	BES	Finlayson et al.[73]	NS	↑
	BES	Nasser, Gluck and Geliebter[124]	NS	NS
	BES	Stinson, Votruba, Venti, Krakoff, Gluck and Perez[98]	NS	↑
		Total	3 NS 4 ↑	4 NS 3 ↑
Eating disorders	EDDS	Anderson, Reilly, Schaumberg, Dmochowski and Anderson[58]	NS	↑
	EDI-2	Long, Meyer, Leung and Wallis[125]	NS	
		Total	2 NS	1 ↑
Food addiction	YFAS 2.0	Schulte, Sonneville and Gearhardt[126]	NS	NS
		Total	1 NS	1 NS

TABLE 2 (Continued)

Eating behavior trait	Questionnaire used to assess eating behavior trait	Cross-sectional study reference	Associations with	
			EI	BMI
Eating self-efficacy	WEL	Vijayvargiya, Chedid, Wang, Atieh, Maselli, Burton, Clark, Acosta and Camilleri[127]	↓	
		Total	1 ↓	
Reward-related eating	RED-X5 RED-9	Vainik, Eun Han, Epel, Janet Tomiyama, Dagher and Mason[55]	↑	↑
	RED-13	**Total**	1 ↑	1 ↑
Total scores	TFEQ	Bellisle and Dalix[128]	NS	NS
	DEBQ	Bellisle and Dalix[128]	NS	NS
	TFEQ	Nolan-Poupart, Veldhuizen, Geha and Small[110]	NS	
		Total	3 NS	2 NS

Note: blank = outcome was measured but the data was not available as authors were contacted but did not reply, NS = non-significant, NS* = significant association with body fat or body weight, ↑ = significance positive association, ↓ = significant negative association,
[a]= reverse coded. If two results are presented for one outcome (e.g., NS and ↑), the effect differed depending on the group or condition tested.

measure restraint ($p < 0.001$, Table S3). For the TFEQ, RRS and EDE-Q, restraint was negatively correlated with EI. Whereas, for the RS and DEBQ, restraint was positively correlated with EI. A random-effects meta-regression was undertaken to test for differences in effect sizes between questionnaires used to measure restraint and EI. The meta-regression was significant ($p < 0.05$); however, TFEQ was the only variable that was significantly associated with EI ($p < 0.01$). Further subgroup analyses revealed that the effect of restraint on EI was not significantly influenced by the number of test meals (one vs. multiple test meals, $p = 0.103$) or BMI group (healthy, overweight, obese, $p = 0.553$). Lastly, the association between restraint and EI was influenced by a preload. Consuming a preload was associated with increased EI, while not consuming a preload was associated with decreased EI ($p = 0.040$, see Table S4).

Meta-analysis of 32 studies ($n = 1869$) showed that restraint was positively correlated with BMI, and this effect was moderate ($r = 0.20$ [0.12, 0.28], $p < 0.001$, Figure 4). Heterogeneity was moderate ($I^2 = 61.2\%$, $Q = 79.86$, $p < 0.001$). Four outliers were identified.[58,79,89,100] Without these studies included, there was no change in the overall effect size ($r = 0.20$ [0.13, 0.26], $p < 0.001$). However, heterogeneity decreased ($I^2 = 34.8\%$, $Q = 41.38$, $p = 0.038$). Using the leave-one-out method, no studies were identified as influential. The funnel plot (Figure S4) suggested little evidence of publication bias, no missing studies were identified, and Egger's test was non-significant ($p = 0.753$). The effect of restraint on BMI did not depend on the type of questionnaire used to measure restraint ($p = 0.103$).

3.3.5 | Control of eating

Dalton, Finlayson, Blundell and Hill[47] found that craving control and positive mood were negatively associated with EI ($r = -0.20$, $p < 0.05$, $r = -0.21$, $p < 0.05$) and BMI ($r = -0.31$, $p < 0.001$, $r = -0.23$, $p < 0.01$) respectively, whereas craving for sweet foods

was positively associated with EI ($r = 0.40$, $p < 0.001$) and BMI ($r = 0.23$, $p < 0.01$).

3.3.6 | Hedonic hunger

A meta-analysis of 4 studies ($n = 183$) found no significant correlation between hedonic hunger and EI ($r = 0.13$ [−0.08, 0.33], $p = 0.147$). Additionally, a meta-analysis of 2 studies ($n = 92$) also found a non-significant association between hedonic hunger and BMI ($r = 0.05$ [−1.00, 1.00], $p = 0.868$).

3.3.7 | Food craving

Martin et al.[111] reported that scores on the FCI were associated with increased total EI ($r = 0.22$, $p < 0.05$); however, there was no data for the effect of FCI on BMI.

3.3.8 | Susceptibility to hunger

A meta-analysis of 6 studies ($n = 362$) found susceptibility to hunger was positively associated with EI, and this effect was moderate-to-large ($r = 0.27$ [0.19, 0.35], $p < 0.001$, see Figure S5). Heterogeneity was low ($I^2 = 0.0\%$, $Q = 2.05$, $p = 0.843$). No outliers or influential cases were identified. Three missing studies were identified to the left (adjusted $r = 0.22$ [0.13, 0.31], $p < 0.001$). A meta-analysis of 3 studies ($n = 245$) found a moderate positive correlation between susceptibility to hunger and BMI ($r = 0.20$ [0.11, 0.28], $p = 0.011$; Figure S6). Heterogeneity was small ($I^2 = 0.0\%$, $Q = 0.20$, $p = 0.903$). No outliers or influential cases were identified. Two missing studies were identified to the left (adjusted $r = 0.17$ [0.11, 0.23], $p = 0.002$).
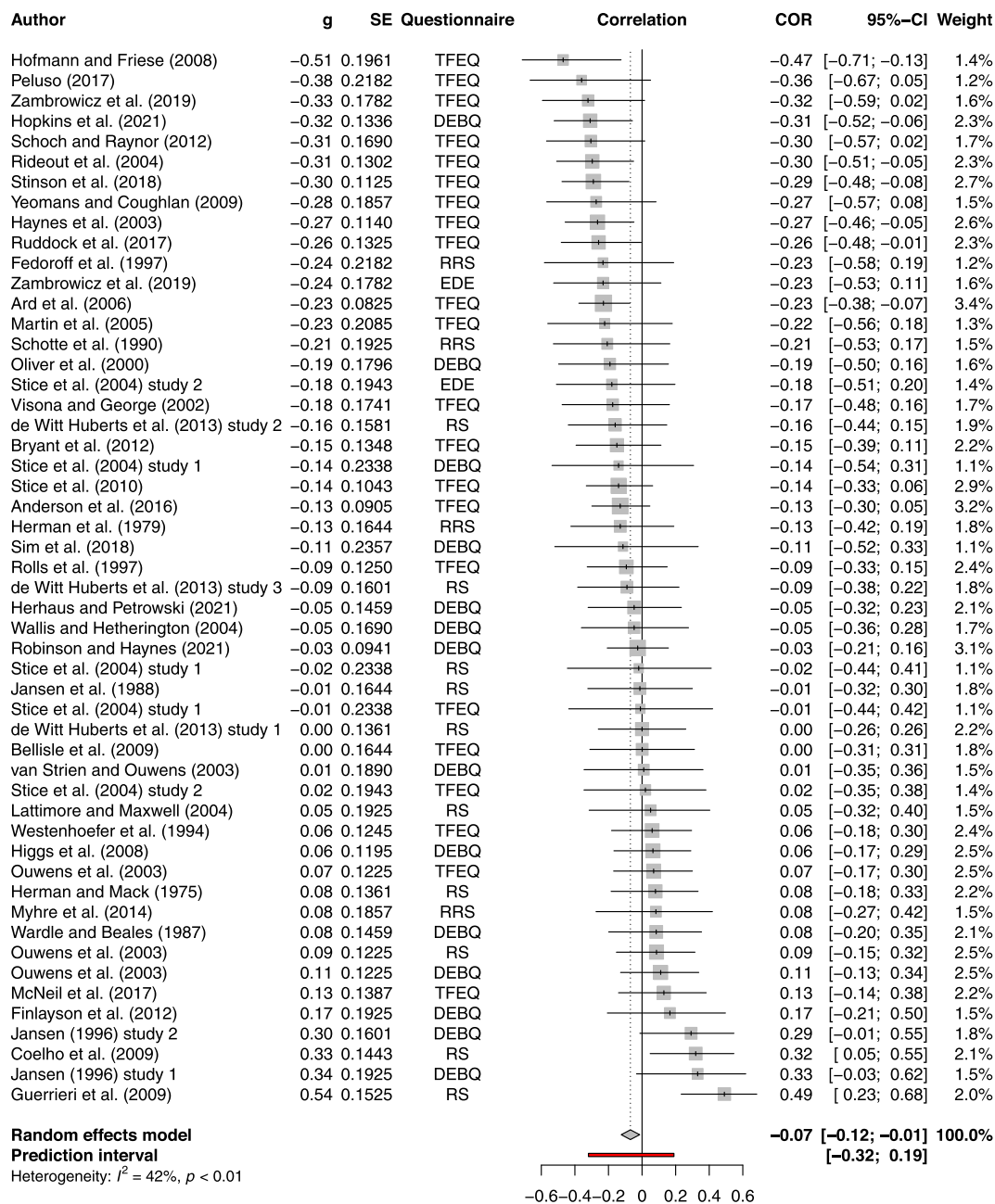
Author	g	SE	Questionnaire	Correlation	COR	95%–CI	Weight
Hofmann and Friese (2008)	−0.51	0.1961	TFEQ		−0.47	[−0.71; −0.13]	1.4%
Peluso (2017)	−0.38	0.2182	TFEQ		−0.36	[−0.67; 0.05]	1.2%
Zambrowicz et al. (2019)	−0.33	0.1782	TFEQ		−0.32	[−0.59; 0.02]	1.6%
Hopkins et al. (2021)	−0.32	0.1336	DEBQ		−0.31	[−0.52; −0.06]	2.3%
Schoch and Raynor (2012)	−0.31	0.1690	TFEQ		−0.30	[−0.57; 0.02]	1.7%
Rideout et al. (2004)	−0.31	0.1302	TFEQ		−0.30	[−0.51; −0.05]	2.3%
Stinson et al. (2018)	−0.30	0.1125	TFEQ		−0.29	[−0.48; −0.08]	2.7%
Yeomans and Coughlan (2009)	−0.28	0.1857	TFEQ		−0.27	[−0.57; 0.08]	1.5%
Haynes et al. (2003)	−0.27	0.1140	TFEQ		−0.27	[−0.46; −0.05]	2.6%
Ruddock et al. (2017)	−0.26	0.1325	TFEQ		−0.26	[−0.48; −0.01]	2.3%
Fedoroff et al. (1997)	−0.24	0.2182	RRS		−0.23	[−0.58; 0.19]	1.2%
Zambrowicz et al. (2019)	−0.24	0.1782	EDE		−0.23	[−0.53; 0.11]	1.6%
Ard et al. (2006)	−0.23	0.0825	TFEQ		−0.23	[−0.38; −0.07]	3.4%
Martin et al. (2005)	−0.23	0.2085	TFEQ		−0.22	[−0.56; 0.18]	1.3%
Schotte et al. (1990)	−0.21	0.1925	RRS		−0.21	[−0.53; 0.17]	1.5%
Oliver et al. (2000)	−0.19	0.1796	DEBQ		−0.19	[−0.50; 0.16]	1.6%
Stice et al. (2004) study 2	−0.18	0.1943	EDE		−0.18	[−0.51; 0.20]	1.4%
Visona and George (2002)	−0.18	0.1741	TFEQ		−0.17	[−0.48; 0.16]	1.7%
de Witt Huberts et al. (2013) study 2	−0.16	0.1581	RS		−0.16	[−0.44; 0.15]	1.9%
Bryant et al. (2012)	−0.15	0.1348	TFEQ		−0.15	[−0.39; 0.11]	2.2%
Stice et al. (2004) study 1	−0.14	0.2338	DEBQ		−0.14	[−0.54; 0.31]	1.1%
Stice et al. (2010)	−0.14	0.1043	TFEQ		−0.14	[−0.33; 0.06]	2.9%
Anderson et al. (2016)	−0.13	0.0905	TFEQ		−0.13	[−0.30; 0.05]	3.2%
Herman et al. (1979)	−0.13	0.1644	RRS		−0.13	[−0.42; 0.19]	1.8%
Sim et al. (2018)	−0.11	0.2357	DEBQ		−0.11	[−0.52; 0.33]	1.1%
Rolls et al. (1997)	−0.09	0.1250	TFEQ		−0.09	[−0.33; 0.15]	2.4%
de Witt Huberts et al. (2013) study 3	−0.09	0.1601	RS		−0.09	[−0.38; 0.22]	1.8%
Herhaus and Petrowski (2021)	−0.05	0.1459	DEBQ		−0.05	[−0.32; 0.23]	2.1%
Wallis and Hetherington (2004)	−0.05	0.1690	DEBQ		−0.05	[−0.36; 0.28]	1.7%
Robinson and Haynes (2021)	−0.03	0.0941	DEBQ		−0.03	[−0.21; 0.16]	3.1%
Stice et al. (2004) study 1	−0.02	0.2338	RS		−0.02	[−0.44; 0.41]	1.1%
Jansen et al. (1988)	−0.01	0.1644	RS		−0.01	[−0.32; 0.30]	1.8%
Stice et al. (2004) study 1	−0.01	0.2338	TFEQ		−0.01	[−0.44; 0.42]	1.1%
de Witt Huberts et al. (2013) study 1	0.00	0.1361	RS		0.00	[−0.26; 0.26]	2.2%
Bellisle et al. (2009)	0.00	0.1644	TFEQ		0.00	[−0.31; 0.31]	1.8%
van Strien and Ouwens (2003)	0.01	0.1890	DEBQ		0.01	[−0.35; 0.36]	1.5%
Stice et al. (2004) study 2	0.02	0.1943	TFEQ		0.02	[−0.35; 0.38]	1.4%
Lattimore and Maxwell (2004)	0.05	0.1925	RS		0.05	[−0.32; 0.40]	1.5%
Westenhoefer et al. (1994)	0.06	0.1245	TFEQ		0.06	[−0.18; 0.30]	2.4%
Higgs et al. (2008)	0.06	0.1195	DEBQ		0.06	[−0.17; 0.29]	2.5%
Ouwens et al. (2003)	0.07	0.1225	TFEQ		0.07	[−0.17; 0.30]	2.5%
Herman and Mack (1975)	0.08	0.1361	RS		0.08	[−0.18; 0.33]	2.2%
Myhre et al. (2014)	0.08	0.1857	RRS		0.08	[−0.27; 0.42]	1.5%
Wardle and Beales (1987)	0.08	0.1459	DEBQ		0.08	[−0.20; 0.35]	2.1%
Ouwens et al. (2003)	0.09	0.1225	RS		0.09	[−0.15; 0.32]	2.5%
Ouwens et al. (2003)	0.11	0.1225	DEBQ		0.11	[−0.13; 0.34]	2.5%
McNeil et al. (2017)	0.13	0.1387	TFEQ		0.13	[−0.14; 0.38]	2.2%
Finlayson et al. (2012)	0.17	0.1925	DEBQ		0.17	[−0.21; 0.50]	1.5%
Jansen (1996) study 2	0.30	0.1601	DEBQ		0.29	[−0.01; 0.55]	1.8%
Coelho et al. (2009)	0.33	0.1443	RS		0.32	[0.05; 0.55]	2.1%
Jansen (1996) study 1	0.34	0.1925	DEBQ		0.33	[−0.03; 0.62]	1.5%
Guerrieri et al. (2009)	0.54	0.1525	RS		0.49	[0.23; 0.68]	2.0%
Random effects model					**−0.07**	**[−0.12; −0.01]**	**100.0%**
Prediction interval						[−0.32; 0.19]	
Heterogeneity: $I^2 = 42\%$, $p < 0.01$				−0.6 −0.4 −0.2 0 0.2 0.4 0.6			

FIGURE 3 Forest plot of the effect of restraint on EI

3.3.9 | External eating

A meta-analysis of 6 studies ($n = 583$) found that external eating was positively correlated with EI, and this effect was moderate ($r = 0.17$ [0.07, 0.27], $p = 0.007$, see Figure S7). Heterogeneity was low ($I^2 = 0.0\%$, $Q = 4.46$, $p = 0.485$). Two influential studies were identified.[115,116] With these studies removed, the effect size slightly increased ($r = 0.18$ [0.01, 0.34], $p = 0.044$). Heterogeneity was low ($I^2 = 0.0\%$, $Q = 2.21$, $p = 0.531$). One missing study was identified to the left (adjusted $r = 0.16$ [0.06, 0.26], $p = 0.008$). A meta-analysis of 4 studies ($n = 269$) found no significant correlation between external eating and BMI ($r = -0.08$ [−0.28, 0.12], $p = 0.285$).

3.3.10 | Emotional eating

A meta-analysis of 10 studies ($n = 608$) found a small-to-moderate, positive correlation between emotional eating and EI ($r = 0.12$ [0.00, 0.24], $p = 0.042$, see Figure S8). Heterogeneity was moderate ($I^2 = 32.1\%$, $Q = 13.26$, $p = 0.151$). No influential studies were identified. The funnel plot did not suggest any publication bias (Figure S9), one missing study was identified to the left (adjusted $r = 0.11$ [−0.02, 0.23], $p = 0.088$) and the Egger's regression test was non-significant ($p = 0.800$). The effect of emotional eating on EI was not influenced by the number of test meals ($p = 0.342$). A meta-analysis of 10 studies ($n = 737$) found that emotional eating
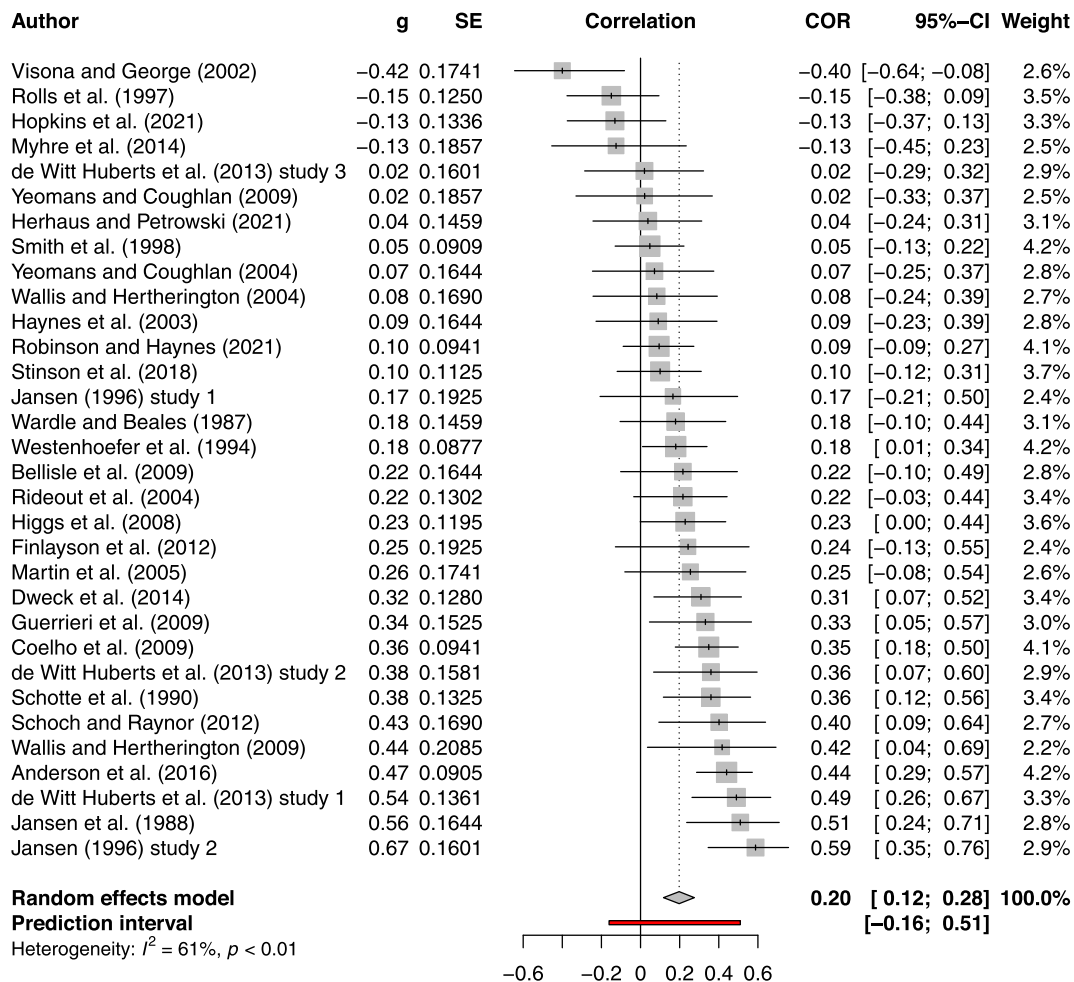
Author	g	SE	Correlation	COR	95%–CI	Weight
Visona and George (2002)	−0.42	0.1741		−0.40	[−0.64; −0.08]	2.6%
Rolls et al. (1997)	−0.15	0.1250		−0.15	[−0.38; 0.09]	3.5%
Hopkins et al. (2021)	−0.13	0.1336		−0.13	[−0.37; 0.13]	3.3%
Myhre et al. (2014)	−0.13	0.1857		−0.13	[−0.45; 0.23]	2.5%
de Witt Huberts et al. (2013) study 3	0.02	0.1601		0.02	[−0.29; 0.32]	2.9%
Yeomans and Coughlan (2009)	0.02	0.1857		0.02	[−0.33; 0.37]	2.5%
Herhaus and Petrowski (2021)	0.04	0.1459		0.04	[−0.24; 0.31]	3.1%
Smith et al. (1998)	0.05	0.0909		0.05	[−0.13; 0.22]	4.2%
Yeomans and Coughlan (2004)	0.07	0.1644		0.07	[−0.25; 0.37]	2.8%
Wallis and Hertherington (2004)	0.08	0.1690		0.08	[−0.24; 0.39]	2.7%
Haynes et al. (2003)	0.09	0.1644		0.09	[−0.23; 0.39]	2.8%
Robinson and Haynes (2021)	0.10	0.0941		0.09	[−0.09; 0.27]	4.1%
Stinson et al. (2018)	0.10	0.1125		0.10	[−0.12; 0.31]	3.7%
Jansen (1996) study 1	0.17	0.1925		0.17	[−0.21; 0.50]	2.4%
Wardle and Beales (1987)	0.18	0.1459		0.18	[−0.10; 0.44]	3.1%
Westenhoefer et al. (1994)	0.18	0.0877		0.18	[0.01; 0.34]	4.2%
Bellisle et al. (2009)	0.22	0.1644		0.22	[−0.10; 0.49]	2.8%
Rideout et al. (2004)	0.22	0.1302		0.22	[−0.03; 0.44]	3.4%
Higgs et al. (2008)	0.23	0.1195		0.23	[0.00; 0.44]	3.6%
Finlayson et al. (2012)	0.25	0.1925		0.24	[−0.13; 0.55]	2.4%
Martin et al. (2005)	0.26	0.1741		0.25	[−0.08; 0.54]	2.6%
Dweck et al. (2014)	0.32	0.1280		0.31	[0.07; 0.52]	3.4%
Guerrieri et al. (2009)	0.34	0.1525		0.33	[0.05; 0.57]	3.0%
Coelho et al. (2009)	0.36	0.0941		0.35	[0.18; 0.50]	4.1%
de Witt Huberts et al. (2013) study 2	0.38	0.1581		0.36	[0.07; 0.60]	2.9%
Schotte et al. (1990)	0.38	0.1325		0.36	[0.12; 0.56]	3.4%
Schoch and Raynor (2012)	0.43	0.1690		0.40	[0.09; 0.64]	2.7%
Wallis and Hertherington (2009)	0.44	0.2085		0.42	[0.04; 0.69]	2.2%
Anderson et al. (2016)	0.47	0.0905		0.44	[0.29; 0.57]	4.2%
de Witt Huberts et al. (2013) study 1	0.54	0.1361		0.49	[0.26; 0.67]	3.3%
Jansen et al. (1988)	0.56	0.1644		0.51	[0.24; 0.71]	2.8%
Jansen (1996) study 2	0.67	0.1601		0.59	[0.35; 0.76]	2.9%
Random effects model				**0.20**	**[0.12; 0.28]**	**100.0%**
Prediction interval					**[−0.16; 0.51]**	
Heterogeneity: $I^2 = 61\%$, $p < 0.01$						

−0.6 −0.2 0 0.2 0.4 0.6

FIGURE 4 Forest plot of the effect of restraint on BMI

was positively correlated with BMI ($r = 0.19$ [0.13, 0.25] $p < 0.001$). This effect was moderate (Figure S10). Heterogeneity was low ($I^2 = 0.0\%$, $Q = 5.17$, $p = 0.819$). No influential cases were identified. The funnel plot did not suggest any publication bias (Figure S11), No missing studies were suggested, and the Egger's test was non-significant ($p = 0.860$).

3.3.11 | Disinhibition

A meta-analysis of 14 studies ($n = 1,172$) found a moderate positive correlation between disinhibition and EI ($r = 0.19$ [0.14, 0.24], $p < 0.001$, see Figure S12). Heterogeneity was low ($I^2 = 0.0\%$, $Q = 9.74$, $p = 0.715$). Influence diagnostics identified one influential case.[112] With this study removed, the overall effect size increased ($r = 0.21$ [0.14, 0.27], $p < 0.001$). Heterogeneity was low ($I^2 = 0.0\%$, $Q = 8.88$, $p = 0.713$). The funnel plot showed little evidence of publication bias (Figure S13), one missing study was suggested to the right (adjusted $r = 0.20$ [0.14, 0.25], $p < 0.001$), and Egger's test was non-significant ($p = 0.973$). The effect of disinhibition on EI was not influenced by the number of test meals ($p = 0.341$). Meta-analysis of

8 studies ($n = 618$) showed a moderate-to-large, positive correlation between disinhibition and BMI ($r = 0.28$ [0.19, 0.38], $p < 0.001$, Figure S14). Heterogeneity was low ($I^2 = 13.8\%$, $Q = 8.12$, $p = 0.322$). One influential case was identified.[95] Without this study included, there was a small decrease in the overall effect size ($r = 0.25$ [0.16, 0.33], $p < 0.001$). Heterogeneity was low ($I^2 = 0.0\%$, $Q = 3.68$, $p = 0.720$). No missing studies were suggested.

3.3.12 | Binge eating

A meta-analysis of 7 studies ($n = 249$) found a moderate, positive correlation between binge eating and EI ($r = 0.26$ [0.08, 0.43], $p < 0.001$, see Figure S15). Heterogeneity was low ($I^2 = 0.0\%$, $Q = 3.68$, $p = 0.720$). Two influential studies were identified.[98,123] With these studies removed, the overall effect size increased slightly ($r = 0.28$ [0.11, 0.43], $p = 0.010$). Heterogeneity was low ($I^2 = 0.0\%$, $Q = 2.02$, $p = 0.731$). Two missing studies were suggested to the left (adjusted $r = 0.17$ [−0.04, 0.37], $p = 0.098$). A meta-analysis of 7 studies ($n = 277$) found a moderate positive correlation between binge eating and BMI ($r = 0.21$ [0.07, 0.34],

$p = 0.011$, see Figure S16). Heterogeneity was low ($I^2 = 0.0\%$, $Q = 5.30$, $p = 0.506$). No influential studies were identified. One missing study was identified to the right (adjusted $r = 0.23$ [0.09, 0.36], $p = 0.006$).

3.3.13 | Disordered eating

A meta-analysis of 2 studies ($n = 152$) was conducted to test the correlation between eating disorder symptomology and EI. The analysis was non-significant ($r = -0.17$ [-0.98, 0.96], $p = 0.499$).

Only one effect size was available to test the effect of eating disorders on BMI; therefore, a meta-analysis could not be conducted. However, Anderson, Reilly, Schaumberg, Dmochowski and Anderson[58] did report that increased scores on the EDDS were associated with increased BMI ($r = 0.40$, $p < 0.05$). The YFAS 2.0 was not significantly associated with EI or BMI.[126]

3.3.14 | Other EBT

Eating self-efficacy was negatively associated with EI ($r = -0.26$, $p < 0.05$).[127] Three measures of reward-related eating were positively correlated with EI (RED-X5: $r = 0.31$, $p < 0.05$, RED-9: $r = 0.35$, $p < 0.05$, RED-13: $r = 0.32$, $p < 0.05$) and BMI (RED-X5: $r = 0.18$, $p < 0.05$, RED-9: 0.17, $p < 0.06$, RED-13: $r = 0.18$, $p < 0.05$).

3.3.15 | Summary of meta-analyses findings

Figure 5 displays the overall effect sizes for each EBT on EI and BMI. A positive effect size indicates that the EBT is positively correlated with EI or BMI. A negative effect size indicates that the EBT is negatively correlated with EI or BMI. Intuitive eating and eating disorder symptomology are not displayed in Figure 5 due to the small number of studies included in these meta-analyses and the large variability in their correlations with EI and BMI. Figure 6 displays the effect sizes for the subgroup analysis testing the correlation between restraint and EI influenced by the questionnaire used to measure restraint. Error bars in both figures reflect standard error.

4 | DISCUSSION

The aims of this systematic review and meta-analyses were to (1) identify which measures are used to capture EBT, (2) assess how well these measures associate with short term EI and (3), BMI, (4) and evaluate whether some EBT and questionnaires used to measure EBT are better at predicting EI or BMI than others. Sixteen EBT were identified. However, the majority of EBT included were restraint, disinhibition, emotional eating, external eating, and binge eating. Considering the >45 years of research on human eating behavior, this systematic review demonstrates that relatively few studies on EBT have been conducted in relation to indices of objectively measured short-term EI as well as long-term energy balance status (BMI). For most of the EBT
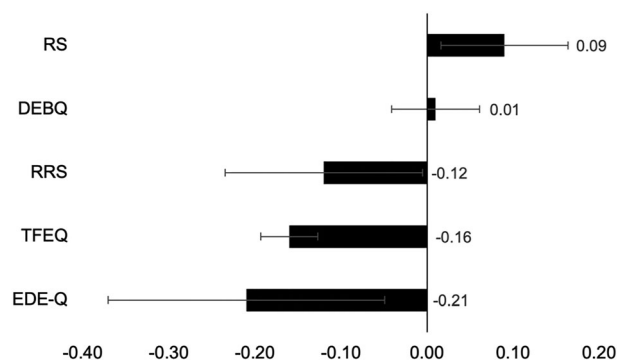
FIGURE 6 Bar graph of the subgroup analysis results, testing the correlation between restraint and EI influenced by the questionnaire used to measure restraint

FIGURE 5 Summary of meta-analyses findings. *Note*: black line = Energy Intake, white line with black border = BMI, error bars indicate standard error, *p < 0.05, **p < 0.01, ***p < 0.001.

identified (aside from restraint), this research has been accomplished in only a small number of studies. Additionally, the majority of traits were measured using a single questionnaire (see Table 1), which were often older measures such as TFEQ or RS. This means that there are additional, typically newer questionnaires with no research that met the inclusion criteria for this systematic review, for example, the Positive and Negative Emotional Eating Scale.[129] Future research should assess the validity of these traits in relation to EI and BMI.

Overall, the meta-analyses demonstrated that EBT do significantly predict both EI and BMI. Effect sizes were generally moderate, with some analyses reaching larger effects. Susceptibility to hunger and binge eating were the strongest predictors of EI, whereas disinhibition was the strongest predictor of BMI. Although intuitive eating was moderately correlated with BMI, this meta-analysis was based on a very small number of studies. If there are not at least two adequately powered studies per meta-analysis, there may not be enough information to contribute an accurate conclusion of evidence about that EBT.[130] Therefore, drawing conclusions about intuitive eating and satiety responsiveness requires caution. Below, the main outcomes of the systematic review are discussed.

4.1 | Restraint

Restraint as a concept relates to a cognitive intention to restrict food intake, which is not necessarily reflected in actual reduction in EI or adherence to a weight reducing diet.[103] This meta-analysis found a positive association between restraint and BMI, which is consistent with previous cross-sectional studies.[131,132] However, negative findings between restraint and BMI have also emerged in the literature.[133] The finding of this systematic review could suggest that although restrained individuals attempt to restrict their food intake, increased restraint puts them at a higher risk of overeating (disinhibition), leading to a positive energy balance and consequently an increased BMI. However, the results of this systematic review do not agree with this prediction. Increased restraint was associated with decreased short-term EI. This finding is more consistent with the interpretation that people with a higher BMI invoke strategies of dietary restraint to manage their weight. Approximately 40% of the adult population report at least one weight management attempt in the preceding 12 months.[134] It is also evident from the weight management literature that the majority of weight management attempts have limited success and are subject to weight regain.[135]

Previous literature examining associations between restraint and EI have also been inconsistent, which is demonstrated in this systematic review as both positive and negative associations were found between restraint and EI. Research has highlighted that the different measures used to assess restraint could be influencing the different outcomes (research question 4). Heatherton, Herman, Polivy, King and McGree[136] suggest that the TFEQ may be better able to identify individuals who are successful in restricting their food intake, whereas the RS is better able to identify individuals who are unsuccessful in dieting. Indeed, the subgroup analysis found a significant effect of questionnaire type, such that the TFEQ was associated with decreased EI, whereas the RS was associated with increased EI (see Appendix). The EDE-Q and TFEQ had the largest effect size therefore suggesting these measures may be better at predicting EI. This analysis suggests that each questionnaire may not be measuring exactly the same construct and generates questions about which scale is best at measuring restraint. The RS, for example, could be contaminated by other constructs such as disinhibition, as items on this scale refer to overeating, for example, "Do you have feelings of guilt after overeating?" This may explain why the RS was positively associated with EI.[103] Moreover, there is also a potential need to re-evaluate what is meant by the construct of restraint. Is restraint a measure of concern controlling intake and its consequences, or could it be a measure of motivation or success in restraining intake like the TFEQ appears to measure or perhaps a combination of these considerations? There is a need to clearly define and achieve consensus about what restraint is and what it is not.

A prediction of restraint theory is that the likelihood of a binge/overeating episode should be increased after consuming a preload only in high restraint individuals. This is because dieters who have just broken their diet are predicted to subsequently overeat.[103,137] In the current analysis, the correlation between restraint and EI was influenced by a preload such that the use of a preload was associated with increased EI, whereas no preload was associated with decreased EI (see Supporting Information). Nevertheless, Ouwens, van Strien and van der Staak[86] reported no significant effect of restraint on EI influenced by a preload. The researchers highlight that not all dieters will show this disinhibition effect; but a particular subgroup might. Restrained eaters can therefore be split into two subpopulations: successful dieters and unsuccessful dieters. Successful dieters are characterized by high restraint and low levels of tendency toward overeating. Unsuccessful dieters are characterized by high restraint and are prone to overeating, meaning they are more likely to show a disinhibition effect after a preload. Westenhoefer, Broeckmann, Münch and Pudel[104] provided evidence for this idea and found that overeating only occurred in participants who displayed high scores on both restraint and disinhibition, as measured by the TFEQ.

More recent research such as Bryant, Caudwell, Blundell, Hopkins and King[66] and Chambers and Yeomans[67] have tested this effect by splitting participants into four groups based on their restraint (high vs. low; HR vs. LR) and disinhibition (high vs. low; HD vs. LD) scores using the TFEQ (HD/HR, HD/LR, LD/HR, LD/LR). A limitation of the current systematic review is that effect sizes were pooled so that high restraint included high and low disinhibition and low restraint included both high and low disinhibition. By not keeping the four groups separate, the analysis may have been insensitive to the effects of differing disinhibition levels. Consequently, future research could conduct a multi-level meta-analysis of restraint on EI, which can account for the influence of other variables such as disinhibition and emotional eating. Based on these findings, one must consider that restraint itself may not be a homogenous construct. Westenhoefer, Broeckmann, Münch and Pudel[104] proposed that restraint can be split into rigid and flexible control, with rigid control

relating to an all-or-nothing approach. In contrast, flexible control reflects a less stringent approach to restriction of intake. These subscales could reflect successful and unsuccessful dieters and may better account for the differing effects of restraint on EI. Unfortunately, only two studies in this review[66,104] split restraint into flexible and rigid control and therefore testing the validity of this concept is currently not possible. Overall, this systematic raises questions about the current definition of restraint and whether it should be altered. If restraint is associated with increased BMI, then attempting to restrain intake as a dietary approach to weight loss may not be effective and other approaches should be utilized.

4.2 | Emotional eating

Another interesting finding of this systematic review was that emotional eating was positively correlated with short term EI and BMI, although there were two studies in the meta-analysis that found a negative correlation between emotional eating and EI.[71,101] The small-to-moderate effect size could have been influenced by the inclusion of only control conditions in this systematic review. Conditions that attempted to influence the emotional state of participants were excluded to reduce potential contaminates of the specific emotional eating trait effect. However, studies have shown that emotional eaters increased their food intake after a negative mood induction, compared with a neutral or positive mood induction.[119,138] A limitation of this systematic review was that only one study presented data for the positive and negative subscales of emotional eating,[116] and therefore the influence of positive or negative emotional eating could not be assessed. Further research should look to test systematically whether emotion valence, as well as emotion induction conditions increase EI in high emotional eaters versus low emotional eaters.

4.3 | Disinhibition

The overall finding that disinhibition was positively associated with short-term EI and BMI supports previous research[6,9] and suggests that associations between uncontrolled eating and food intake are more consistently measured by scales capturing disinhibition, potentially because disinhibition is a 'pure' measure of uncontrolled eating. These findings suggest that increased disinhibition is an indicator of risk for potential weight gain and could be targeted in weight loss interventions characterize participants at risk of weight regain. Disinhibition could influence weight regain[139] and research has found that participants who maintained weight loss were characterized by lower disinhibition scores.[140] Niemeier, Phelan, Fava and Wing[141] found that higher internal disinhibition predicted less successful weight loss and studies have consistently shown that successful weight loss is associated with a decrease in disinhibition.[142–144] If weight loss interventions can successfully target and reduce participants' uncontrolled eating behavior (disinhibition), this approach may improve weight outcomes.

Furthermore, binge eating and susceptibility to hunger were also consistent predictors of EI and BMI and may be useful constructs to target in weight loss interventions. Assessing whether other traits are associated with behavior change is another important direction for future research. For example, studies have found that higher baseline emotional eating was associated with more weight gain over time,[145] meaning emotional eating could also be targeted in weight loss interventions. Mindfulness-based interventions have also been used to help participants decrease their tendency to eat in response to negative emotions.[146] Future research should assess which traits are prospectively associated with weight change or weight maintenance, as well as investigating the long-term efficacy of interventions utilizing EBT. Ultimately, disinhibition is a robust EBT that should be used in weight loss interventions and further research should strive to find ways to reduce levels of disinhibition in those scoring high on this subscale.

4.4 | Methodological comments

This systematic review included only laboratory-based measures of EI because there is substantial evidence that self-report measures are susceptible to misreporting.[10] However, laboratory-based measures of EI are highly susceptible to experimental design and demand characteristics. For example, Long, Meyer, Leung and Wallis[125] highlight that eating in a laboratory is an unnaturalistic setting and could distract and impede a participant's focus on internal signals of hunger and satiety, which could influence their EI. Another concern relates to how well one single eating episode can generalize to usual eating behavior.[59] Snacking once in a test meal (often involving unusual foods) may not be an accurate reflection on a participants normal EI. Fourteen studies did test EI over multiple test meals, which helps to reduce this limitation. However, there were still 68 studies that tested a single eating episode and therefore, multiple test meal methods are not commonplace in eating behavior research. There are also issues relating to the 'observer effect', whereby participants behavior is biased by the awareness that they are being observed and that they are participating in a food-related study.[147] Studies rarely attempt to disguise that a meal is being used to measure food consumption and this transparency may alter the way a participant eats.[14] Laboratory measures of food intake may have limited generalizability to normal every day eating behavior. However, the current meta-analyses generalize over multiple test designs and test meals which helps to overcome the role of specific research designs.

Another limitation of many studies included in this systematic review is the potential for other variables measured to contaminate the EI outcome. Although studies that included potential contaminates were excluded, there were still some tasks which may have influenced the outcomes. For example, Coelho, Polivy, Herman and Pliner,[68] included a control condition that required participants to complete an arithmetic problem-solving task and a word-recall task. The researchers found that the participants could not complete the

test within the time provided and could have exposed the participants to task failure or ego threat which may have affected the participant mood/emotions.

4.5 | Conceptual comments

An important consideration of EBT is uncertainty over the extent to which individuals are capable of accurately assessing their own eating behavior, for example, emotional eating. Evers, de Ridder and Adriaanse[117] suggests a 'triple recall bias', whereby people are generally unable to perceive their own behavior, they underreport their EI and personality disturbances, and retrospective emotional ratings are known to be highly sensitive to recall bias. Consequently, questionnaires that measure emotional eating are asking participants to recall their negative or positive emotions, food intake and association between both, all three of which may be biased. It is therefore possible that in some populations, for example, the elderly and young children, recall methods may not yield accurate findings and as such, should not be used. However, recommendations for specific population where EBT assessments should not be measured is beyond the scope of this analysis. The triple recall bias can also be extended to other psychological EBT, which raises concerns over their construct validity and questions whether EBT measuring what they were designed to measure? Interestingly, new developments in real time digital tracking of energy balance behaviors,[148–152] digital ecological momentary assessments and mobile video recording[153] could be a new avenue for more ecological assessments of EI to capture EBT.

Most studies test the validity of EBT against very short-term EI, often over one test day. In order to relate EBT to long-term outcomes, EI and BMI need to be measured longitudinally. This also holds true for studies that aim to assess how EBT change in weight management interventions. In the short term, EBT are not expected to change because they are long-term processes. Therefore, to examine how EBT are associated with behavior change, they also need to be measured over a longer period of time.

5 | CONCLUSIONS

The outcome of this review has demonstrated that many EBT are associated with short-term EI and BMI, with disinhibition, susceptibility to hunger and binge eating having the largest effect sizes for EI and BMI. These findings highlight the potential use of these EBT as phenotypic markers of susceptibility to overconsume, develop obesity, or to influence outcomes in weight management interventions. Dietary restraint is evidently a complex construct and further research with preload conditions and separate subscales are needed to fully understand its effect on EI. The effect of emotional eating may have been limited by not including mood or stress induction conditions. However, this review still indicates it plays a role in EI and BMI. Importantly, there are methodological and conceptual issues with EBT

that need to be stressed when utilizing these traits in eating behavior research. This does not mean they should not be used but a greater focus on objective indices of what such traits should predict (food intake and EI, BMI or weight change) might improve their use in explaining eating behavior and energy balance in the wider population.

CONFLICTS OF INTEREST

Pr. James Stubbs consults for Slimming World UK through The University of Leeds. Slimming World was not involved in the analysis or interpretation of this review.

AUTHOR CONTRIBUTIONS

CD, JS, GF, and MH performed the literature search, study selection, data extraction, and quality assessment. CD performed the meta-analysis and drafted the manuscript. All authors critically revised the manuscript.

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SUPPORTING INFORMATION

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