Implicit bias to food and body cues in eating disorders: a systematic review

Georgios Paslakis1,2,3 · Anne Deborah Scholz-Hehn4 · Laura Marie Sommer5 · Simone Kühn4

Received: 31 March 2020 / Accepted: 27 July 2020 / Published online: 8 August 2020
© The Author(s) 2020

Abstract
Background Rigid, restrictive eating patterns, fear of gaining weight, body image concerns, but also binge eating episodes with loss of control leading to overweight, at times followed by compensatory measures to control weight, are typical symptoms in eating disorders (EDs). The regulation of food intake in EDs may underlie explicit processes that require cognitive insight and conscious control or be steered by implicit mechanisms that are mostly automatic, rapid, and associated with affective—rather than cognitive—processing. While introspection is not capable of assessing implicit responses, so-called indirect experimental tasks can assess implicit responses underlying a specific behavior by-passing the participant’s consciousness. Here, we aimed to present the current evidence regarding studies on implicit biases to food and body cues in patients with EDs.

Methods We performed a systematic review (PRISMA guidelines). We included controlled studies performed in clinical ED cohorts (vs. healthy control subjects or another control condition, e.g., restrictive vs. binge/purge AN) and using at least one indirect assessment method of interest.

Results Out of 115 screened publications, we identified 29 studies fulfilling the eligibility criteria, and present a synthesis of the essential findings and future directions.

Conclusion In this emerging field of research, the present work provides cornerstones of evidence highlighting aspects of implicit regulation in eating disorders. Applying both direct (e.g., self-reports) and indirect measures for the assessment of both explicit and implicit responses is necessary for a comprehensive investigation of the interplay between these different regulatory mechanisms and eating behavior. Targeted training of implicit reactions is already in use and represents a useful future tool as an add-on to standard psychotherapeutic treatments in the battle against eating disorders.

Evidence level 1 (systematic review).

Keywords Anorexia nervosa · Bulimia nervosa · Binge eating disorder · Approach avoidance task · Implicit · Bias

Introduction

The terms implicit vs. explicit determine the degree of automatism of a particular response to specific cues [1]. An explicit response to a cue is target oriented and, thus, subject to attentional or strategic control and conscious awareness. All responses that are rapid/automatic, spontaneously induced and most probably lie outside a person’s awareness are implicit. The interplay between implicit and explicit responses forms behavior, e.g., food intake. In the realm of food intake, physiological (homeostatic) mechanisms are implicit [2]. Deliberate attempts to psychologically override natural regulatory processes like in restricted food intake (“diet”) are by definition explicit.
Direct methods, mostly self-reports upon request, assess explicit responses. While introspection is not capable of assessing implicit responses, so-called indirect experimental tasks can assess implicit responses underlying a specific behavior without the need to access the participant’s consciousness [1]. In such tasks, typically response times (i.e., the time between presentation of a cue and the actual response) serve as a surrogate for the strength of the association between cue and response. Thus, faster response times are indicative of a stronger cue-to-response association. Differences in response times, e.g., when it comes to the experimental approach vs. avoidance of cues, are defined as implicit (approach or avoidance) biases.

Direct, explicit measures are a necessary tool in behavioral and healthcare research as they enable quick and easy data collection in large samples and may also be used to measure constructs otherwise difficult to obtain by means of behavioral or physiological measures (e.g., introspection as a trait). On the other hand, response bias in explicit data collection is a well-known and widely discussed phenomenon. Beside the multiple reasons for which self-reported attitudes and behaviors may be biased (reduced introspective ability, cognitive distortions due to the clinical condition, e.g., overweight patients with Anorexia Nervosa feeling “fat” or denying having fat phobia, social desirability bias, or recall bias), response bias is subject to change following an intervention. This “response-shift bias” [3] occurs when an intervention changes an individual’s understanding or awareness of the target concept [4], thus affecting the bias at each measurement point. Also, behaviors may be influenced by the process of self-monitoring per se and could operate differently among those who are not self-monitoring their behaviors. In this sense, studies have reported that self-monitoring of exercise behaviors and physical activity levels are positively associated [5]. Based on dual-process theory [6], implicit and explicit bias capture different underlying processes, which drive different behavioral manifestations [7, 8]. Thus, even though explicit tools such as self-report questionnaires or the ecological momentary assessment (EMA) may help collect significant amounts of data, when possible, examining both types of biases may shed light onto how normative behavior (eating behavior) may become non-normative (e.g., restrictive eating). Discrepancies between implicit and explicit biases have been associated with unhealthy eating behavior and disinhibited eating [9, 10]. Implicit and explicit biases may independently predict behavior [11]. Several studies have examined implicit biases to food in different phenotypes among healthy cohorts (dieters vs. non-dieters, high food cravers vs. low food cravers, etc.), and found discrepancies between explicit and implicit biases. Restrained eaters displayed a stronger positive implicit bias to high-calorie foods as opposed to their negative explicit evaluations [12, 13]. A study comparing restrained to unrestrained eaters found a stronger approach bias to high-calorie food in restrained eaters [14]. Restricting food intake for the sake of a diet, a paradigmatic explicit behavior of cognitive control, goes along with enhanced cortical activity [15]. On the other hand, breaking a diet (“diet failure”) has been associated with an increase in the (implicit) reward sensitivity of food [16]. Such findings could be used to explain disinhibited eating in dieters who occasionally break their diet. Regarding emotional eating, indirect assessment methods have also shown a differential implicit bias pattern to food cues between high and low emotional eater [17, 18].

Next to indirect assessment studies using food cues, there are also studies that applied body-related cues and demonstrated implicit pro-thin/anti-fat bias [19–21]. These biases were associated with higher levels of disordered eating [20–22]. In fact, implicit biases were predictive of eating disorder (ED)-related symptomatology above and beyond the corresponding explicit biases [22]. Finally, in females with self-reported ED-traits, symptoms regarding body dissatisfaction were consistently associated with both explicit [23] and implicit [24] negative biases to food.

Thus, several studies showed differential patterns of implicit vs. explicit biases to food and body cues in non-clinical cohorts and associated these patterns with ED-related psychopathology. It is, therefore, not surprising that implicit and explicit aspects of eating behaviors have steadily found their way into clinical contexts as well. It was hypothesized that implicit biases and discrepancies to explicit ratings might be able to explain some of the key clinical characteristics of patients with EDs. Patients with Anorexia Nervosa (AN) display a high degree of self-control that helps them keep an explicit dieting goal even in the presence of a strong physiological urge to approach food [25]. Some authors have suggested that food has lost its incentive (implicit) value in patients with the restrictive type AN [26]. The regulation of the drive to intake food is also impaired in obesity, however in the other direction, with the rewarding properties of food being unusually high [27]. Patients diagnosed with Bulimia Nervosa (BN) or Binge Eating Disorder (BED) show frequent disruptions in inhibitory control leading to binge eating episodes despite their efforts to withdraw from such behaviors. In the case of BN and BED in particular, self-regulation abilities are hampered in situations of high emotional intensity (e.g., confrontation with stressors) or when the experienced stimuli are particularly strong (e.g., due to the availability of high palatable and rapidly available food) and disable counter-regulatory, implicit or explicit, mechanisms [28].

In this review, we systematically assessed the current evidence on implicit biases in EDs regarding food and body cues. Although there is an increasing number of studies examining implicit biases in ED cohorts, these studies
are mostly cross-sectional and methodologically heterogeneous. In contrast to a recently published review that focused only on visual attentional biases in individuals with EDs [29], our work pursued a broader approach to this field by considering all available indirect assessment methods. We included controlled studies (ED cohorts vs. healthy controls) that applied at least one indirect bias assessment method. By providing a systematic overview of the relevant literature in the field, we aimed to examine the evidence based on which implicit biases or discrepancies between implicit and explicit biases may explain disordered eating patterns in patients with EDs. Findings may help to adequately design and apply future interventions based on implicit bias modification.

**Materials and methods**

In conducting this updated systematic review, we followed the guidelines of the PRISMA statement (preferred reporting items for systematic reviews and meta-analyses) [30].

**Search strategy**

To carry out the systematic part of this review, we conducted a systematic search (lastly performed on July 6th, 2020) by hand in the PubMed database (www.pubmed.gov) as well as in the Cochrane Central Trials Register using MeSH terms, keywords of interest, and their combinations. Exemplarily, the PubMed search included the following terms: (((((((eating disorder) OR anorexia nervosa) OR bulimia nervosa) OR binge eating disorder) OR OSFED) OR EDNOS)) AND (((((((indirect assessment) OR indirect test) OR indirect task) OR implicit method) OR implicit task) OR implicit assessment) OR implicit association test) OR approach avoidance task) OR implicit association task) OR implicit test)) AND (((bias) OR implicit bias) OR implicit). We have additionally carried out a hand search for relevant articles cross-cited in search results and inspected reference lists to identify further studies of interest.

The studies were categorized into those examining implicit bias to food vs. body cues. Specifically, we addressed the following aspects:

1. Implicit biases in clinical (ED) cohorts: food cues
2. Implicit biases in clinical (ED) cohorts: body image cues

A consort diagram describing the search and selection stages is displayed in Fig. 1.

**Eligibility criteria**

Eligibility criteria were based on the PICOS taxonomy according to the PRISMA statement [30], defining criteria for each of the five domains, i.e., participants (P), interventions (I), comparators (C), outcome (O) and study design (S). We included studies performed in a defined population P (patients with eating disorders) and assessing implicit bias to food and body cues as outcome O. We also only included analytic studies, thus, experimental (e.g., RCTs) and observational analytic studies (e.g., cohort studies) with an intervention I. We also only included studies that examined the rates of outcomes in a comparison group C. A two-step process was used to evaluate the results of the literature search. First, the titles and/or abstracts of all publications mentioned above were independently reviewed by G.P. and A.D.S.-H. prior to the retrieval of full-texts. Second, articles identified eligible for full review were further screened based on specific eligibility criteria. The final decision to include studies in the present work was based on the following criteria: (I) studies including a clinical cohort, thus patients diagnosed with an ED. Studies performed in nonclinical cohorts, e.g., undergraduate students, were not considered for inclusion. However, we discussed studies in nonclinical cohorts with relevant results in this review as well, (II) studies reporting implicit biases using at least one indirect experimental task, (III) studies including a healthy control group or another control condition, e.g., restrictive vs. binge/purge AN, (IV) studies including adults over 18 years of age, and (V) articles written in English. Differences of opinion between both authors were resolved through consensus.

**Participants**

We included studies in adult patients diagnosed with an ED, and only studies including a control group.

**Interventions**

A great variety of indirect tests to assess implicit biases have been developed and are currently in use. Of these, the implicit association task (IAT) is considered the prototype [31]. In this test, participants are presented with cues (mostly words) from 4 different categories (two category pairs, e.g., “sweets/vegetables” and “positive/negative”) and are asked to associate these cues as fast as possible using predefined response options (e.g., by pressing a left key in the case of a cue belonging to “sweets” or “positive” and a right key for “vegetables” or “negative” or vice versa in subsequent runs). As a result, responses to “compatible” associations are faster compared to “incompatible” ones and display biases. Similarly, in the approach avoidance task (AAT), participants are
asked to either push or pull target cues using a joystick or computer mouse, but responding to an irrelevant cue feature (e.g., picture format) and not to the cue itself; the direction of motion gives participants the impression of actually approaching cues by pulling them towards them or avoiding cues by pushing them away [32]. Again, compatible cue x direction of motion pairs led to faster responses compared to incompatible pairs and constitute implicit biases. We did not limit our review to just specific methodologies like the IAT or the AAT and describe additional indirect tasks to assess implicit biases further below within the main part of this review.

Comparators

We have decided to only include studies that have compared a (non-clinical) control group or control condition.

Outcome

Implicit biases to food and body-related cues were the outcomes in all studies included in this review.

Study design

We included not only studies that were cross-sectional but also studies reporting longitudinal data on implicit biases,
e.g., the change in bias following an intervention or ED-specific treatment. Both retrospective and prospective studies were considered; however, no retrospective studies were retrieved. Additionally, we included only controlled studies to be able to draw more adequate conclusions as to the presence or absence of implicit biases in ED cohorts and the inferences thereof with actual eating behaviors.

Results

Study selection

We identified 115 publications through our systematic search and 6 publications through other sources (Fig. 1). After screening, 57 publications remained for the full-text analysis. We then excluded 28 of these publications as they did not fulfill one or more of the eligibility criteria. In the end, 29 studies were included in this present systematic review of the literature. Reasons for exclusion were: studies in adolescents only \((n=5)\), no indirect assessment method \((n=5)\), study in a non-clinical cohort \((n=10)\), lack of a control group \((n=6)\), study protocol \((n=2)\), and review \((n=2)\) (Fig. 1).

Studies investigating implicit biases in clinical (ED) cohorts: food cues

We included \(n=16\) studies that examined implicit biases in ED cohorts employing food cues and fulfilled the eligibility criteria.

In the so-called affective priming paradigm (APM), two words are presented in quick succession and participants read the presented first word (“prime”) and are asked to respond to the second word (“target”). Congruent trials (e.g., palatable prime/positive target) are associated with faster responses than incongruent ones (e.g., palatable prime/negative target). In the study by Roefs et al. [33] using the APM, healthy controls showed an implicit bias for high palatable food cues compared to patients with AN [33]. Also using the affect misattribution procedure (AMP), a computer-based measure of implicit affect in response to disorder-specific cues, patients with AN showed significantly higher negative implicit bias for high- but not low-calorie food [34]. In line with these results, patients with AN and BN showed a higher negative implicit bias to food cues in the AMP compared to a control group [35]. Negative implicit biases to food were predictive of ED symptoms and ED-related behaviors in an assessment 4 weeks later [35].

Our group used the approach avoidance task (AAT) to test the hypothesis that an implicit avoidance bias for high-calorie cues would be found in patients with AN compared to healthy controls, who instead would display an approach bias for high-calorie cues [36]. As the main result, we found that healthy controls showed an approach bias for food cues independent of calorie content, as reflected by faster reaction times in the “pull” compared to the “push” condition; this bias was absent in the group of patients with AN [36]. Seibt et al. [25] examined the effect of food deprivation on the immediate valence and implicit bias to food in a small group of patients with AN and BN and controls using the affective Simon task (AST) [25]. Study participants had to either approach food pictures or avoid them by moving an animated manikin towards a food picture or away from it. The authors found that, regardless of the presence of an ED, the implicit approach bias to food was facilitated by hunger [25]. Finally, using similar procedures, Nejmeier et al. [37] compared the AST with food as a task-irrelevant stimulus against a Stimulus Response Compatibility (SRC) task with food as the task-relevant stimulus that could not be ignored; the authors found a reduced approach bias when food stimuli were task irrelevant but an increased avoidance of food when food stimuli were the task-irrelevant feature [37].

Changes in facial electromyographic activity, skin conductance and heart rate mirroring implicit responses were assessed in patients with AN and controls in the study by Soussignan et al. [38]. The authors exposed all participants to palatable food cues following a subliminal exposure to facial emotional cues (e.g., fear or disgust). Subliminal fear cues increased facial electromyographic activity in response to food in AN compared to controls [38]. Unconscious fear may, thus, increase the negative bias to food in patients with AN.

Despite lower implicit bias for palatable food in an IAT in a clinical ED group in the study by Mattavelli et al. [39], three sessions with transcranial direct current stimulation (tDCS) on frontal and occipito-temporal cortices were shown to increase implicit biases specifically to food cues compared to control women. This effect was specific for food but not body cues [39].

Cowdrey et al. [40] examined the motivational (wanting) bias to high- and low-calorie food at both an implicit and an explicit level in females at different illness phases of AN and healthy controls. The authors applied a forced-choice methodology, during which patients had to select from a pair of food cues the one that they most wanted to eat at that moment using a keyboard response. By covertly measuring reaction times to the food cues, interpreted as a degree of preference, patients were unaware of their implicit bias to food assessed on the task. The authors showed that patients with acute as well as weight-restored AN demonstrated significantly lower implicit wanting for high-calorie foods and higher implicit wanting for low-calorie foods; the opposite was the case in controls. Patients with acute AN reported significantly lower explicit wanting for high-calorie foods than the other groups [40].
Werthmann et al. [41] compared adults with AN to adults without AN applying the visual probe task. In this task, two pictures are presented next to each other, following a target cue replacing one of the pictures. Participants are asked to identify the position of the target cue. According to the theory behind the task, participants will respond faster to the target cue if it appears in the place of the picture that had captured their attention the most. Thus, response latencies display an indirect measure of attention. The authors showed that the patient group avoided maintaining attention on food vs. non-food cues [41].

Nonetheless, there is also deviating evidence. In the word stem completion task, participants are given the first few letters of a word and are required to complete the word as quickly as possible. This way, schema activation rather that activation of explicit knowledge is elicited. Patients with AN showed a strong explicit memory bias for words related to AN (e.g., thighs, thin, kilo, chocolate) compared to controls; however, no similar bias in the implicit word stem completion task was found in the study by Hermans et al. [42]. Applying the startle eyeblink modulation paradigm to assess appetitive and aversive responses in patients with EDs, Friederich et al. [43] found that patients with AN had a startle response to food cues that did not differ from controls [43].

In contrast to findings in AN [41], binge eaters with obesity exhibited higher latencies to disengage attention away from food cues in the visual probe task compared to obese participants without binge eating episodes [44]. In a previous study of our group, we found a significant avoidance bias to low-calorie food in patients with BED, not different to the bias displayed in the control group. To explain the surprising lack of differences between patients with BED and controls, we argued that biases underlying binges may not be captured adequately under laboratory conditions, thus outside the context of an actual bingeing episode [45]. Leehr et al. [46] followed a different approach, with facial electromyography recordings suggestive of automatic, rapid (implicit) responses, and reported different results. The authors examined normal-weight controls vs. overweight participants vs. overweight patients with BED. They found that all groups showed a negative implicit bias to food cues (compared to non-food cues). However, the groups reported an explicit positive bias to food cues (compared to non-food cues). The strength of the explicit bias was overweight + BED > overweight participants > normal-weight participants [46].

The double-blind randomized controlled trial by Brockmeyer et al. [47] compared, real, vs., sham “ABM” (approach bias modification) training sessions. Over the course of 4 weeks, participants with BN and BED were trained (or not) to avoid food cues. Training was determined by a higher number of avoidance over approach movements to food, while in the sham training participants had an equal number of approach and avoidance movements to food and non-food cues. A total of 10 training sessions were not able to influence approach and attention bias to food or actual food intake, although the real ABM condition was associated with more significant reductions in ED symptoms than sham ABM [47].

All studies presented in 3.2 are shown in Table 1.

### Studies investigating implicit biases in clinical (ED) cohorts: body cues

We included $n = 18$ eligible studies that examined implicit bias to body cues in ED cohorts, including $n = 5$ studies that examined food and body cues and were already presented in “Studies investigating implicit biases in clinical (ED) cohorts: food cues” [34, 35, 39, 42, 43].

No differences in startle responses to thin female bodies were found between females with AN, BN, and controls in the study by Friederich et al. [43], a finding confirmed by Brockmeyer et al. [48] who found no differences between patients with AN and healthy controls in the implicit evaluation of emaciated bodies in an AAT. Interestingly, after replacing the face on body stimuli by the participant’s own face, patients with AN displayed an implicit bias for that manipulated body over the one carrying the standard face [48].

Spring and Bulik [34] hypothesized that patients with AN would display significantly higher negative implicit bias to overweight and significantly higher positive implicit bias to underweight in an affect misattribution procedure (AMP). As expected, patients with AN showed significantly stronger negative implicit bias to overweight cues [34]. In line with these results, patients with AN and BN showed more negative implicit bias to average body stimuli compared to a control group [35].

Smith et al. [49] determined whether patients with AN associate emaciation with beauty using the lexical decision task, applied to examine biases to emaciated compared to underweight bodies. The authors hypothesized that women with AN primed with emaciation would recognize words associated with “beautiful” faster than women in the control group who were primed with emaciation as well as faster than women with AN primed with thinness. Women with AN showed a stronger association between emaciation and beauty than control women. Additionally, ED symptoms were found to significantly predict the robustness of the association between emaciation and beauty, but, paradoxically, also between emaciation and ugliness [49]. Other authors have shown that negative implicit bias to overweight—rather than positive bias to ultra-thin role models—appears to be a key issue in AN [50].

These results are in keeping with previous results obtained using affective priming in patients with AN,
Table 1 The table displays current research findings with regard to indirect measures and implicit biases in the field of food-related cues in patients with eating disorders. For details please refer to the main text.

| Publication | Participants | Purpose | Instruments (indirect measures) | Control group or condition | Main outcome |
|-------------|--------------|---------|--------------------------------|-----------------------------|--------------|
| Implicit bias in clinical cohorts: food | | | | | |
| [42] | $N=12$ inpatients with AN and $N=12$ nondieting controls | To test the activation of anorexia-related concepts compared to unrelated concepts in patients with AN and controls | Implicit word completion test | Healthy controls | The data did not support an implicit memory bias for AN-related words in patients with AN |
| [33] | $N=22$ patients with AN vs. $N=27$ unrestrained lean controls (experiment 1), $N=27$ obese participants vs. $N=27$ unrestrained lean controls (experiment 2) | To test the sensitivity to the palatability of foods in patients with AN and obese participants compared to unrestrained lean controls | Affective Priming Paradigm | Un-restrained lean controls | In contrast to controls, patients with AN did not show a bias for palatable (low- vs. high-fat) foods (experiment 1). Obese participants showed a bias for low-fat over high-fat foods; this result was interpreted as the result of health concerns in the obese cohort (experiment 2) |
| [43] | $N=30$ females with an ED ($N=15$ AN, $N=15$ BN) and $N=30$ female controls | To examine appetitive and aversive responses to food and body cues in patients with EDs | Acoustically elicited Startle Eye-blink Modulation (SEM) | Healthy controls | Females with BN showed an appetitive response (startle inhibition) to food cues relative to neutral cues, while patients with AN showed a generalized failure to activate the appetitive motivational system |
| [38] | $N=16$ females with AN, $N=25$ female controls | To examine the influence of subliminal emotional processes on bias to food in AN | Subliminal exposure to facial expressions (happy, disgust, fear, and neutral faces) combined with facial electromyographic activity, skin conductance, heart rate and videotaped facial behavior | Healthy controls | Subliminal fear cues increased the negative bias to food cues in patients with AN |
| [25] | $N=7$ patients with BN and $N=13$ patients with AN (study 3) | To examine how food deprivation influences the immediate valence of food cues and motivational bias for food cues | Affective Simon Task (study 3) | Healthy controls, both satiated and food deprived (study 3) | Food deprivation led to a more positive immediate valence of food items in the IAT and EAST. Approach bias was facilitated for participants tested before lunch compared to those tested afterwards, even in the ED cohort |
| Publication | Participants | Purpose | Instruments (indirect measures) | Control group or condition | Main outcome |
|-------------|--------------|---------|---------------------------------|-----------------------------|--------------|
| [40]        | $N=20$ females with current AN, $N=22$ females with weight-restored AN, $N=22$ females with fully recovered AN and $N=41$ healthy females as controls | To examine implicit and explicit wanting and liking in a group of acute AN and weight-restored AN compared with fully recovered patients with AN and controls | An implicit wanting reaction time measure in a forced-choice procedure | Healthy control group, weight-restored and fully recovered AN patients | Acutely underweight females with AN explicitly wanted high-calorie foods less than the other groups did. Both current and weight-restored groups with AN demonstrated significantly less implicit wanting for high-calorie foods and more implicit wanting for low-calorie foods; the opposite pattern was seen in healthy females |
| [34]        | $N=25$ females with AN ($N=9$ with acute AN, $N=14$ recovered from AN), $N=29$ healthy control females | To test responses to low- and high-calorie cues in patients with AN | AMP | Healthy control group and control group recovered from AN | Patients with AN showed significantly higher negative implicit bias for cues of high- but not low-calorie food, indicating that they do not display negative implicit bias for all foods |
| [36]        | $N=41$ patients with AN and $N=42$ controls | To assess explicit and implicit biases towards low- and high-calorie foods in patients with AN compared to controls | Implicit AAT | Healthy control group | Healthy controls showed an approach bias for food independent of calorie content; this bias was absent in the group of patients with AN |
| [46]        | $N=61$ Obese patients (with and without BED) and healthy controls | To examine implicit bias for food cues vs. non-food cues in obese participants with vs. without BED and controls | Facial electro-myography | Healthy control group | Despite higher explicit negative bias towards food in the group of obese patients with BED compared to the other groups, all groups under investigation showed a negative implicit bias towards food (vs. non-food cues) as assessed using facial electro-myographic recordings |
| [45]        | $N=24$ obese patients with BED (OB-BED), $N=32$ obese participants without BED, $N=25$ healthy controls | To assess explicit and implicit biases towards low- and high-calorie foods in obese participants with BED (OB-BED), obese participants without BED, and controls | Implicit AAT | Healthy control group and group of obese without BED | Both the OB-BED group and healthy controls showed an avoidance bias for pictures of low-calorie food |
| [44]        | $N=19$ obese patients with binge eating and $N=23$ participants without binge eating | To detect attentional bias (slower attentional disengagement) from unhealthy food in obesity in different stages of the attentional process | Computerized Visual Probe Task | Obese participants without binge eating as a control group | Obese patients with binge eating behavior displayed a more pronounced attentional bias towards food than participants without binge eating behavior |
| Publication | Participants | Purpose | Instruments (indirect measures) | Control group or condition | Main outcome |
|-------------|--------------|---------|--------------------------------|---------------------------|--------------|
| [35]        | Patients with AN and BN (N=92) and controls (N=85) | To test if patients with EDs differ from controls in implicit biases to food and body cues and if these biases predict ED symptoms and behaviors over a 4-week period | AMP | Healthy controls | Patients with AN and BN showed a higher negative implicit bias to food compared to controls. Negative implicit biases to food were predictive of ED symptoms and ED-related behaviors in an assessment 4 weeks later |
| [39]        | N=21 females with AN, N=13 females with BN, N=2 females with EDNOS; N=36 healthy control females | To examine the effect of transcranial current stimulation (tCDS) on implicit biases towards food and body cues | IAT | Healthy controls | Three sessions of tCDS led to an increase of implicit bias for food in the ED group. This effect was specific for food cues |
| [41]        | N=39 adults with AN, N=34 adolescents with AN, N=53 adult controls and N=31 adolescent controls | To examine if attention bias to food differs across age and illness duration | Visual Probe Task with concurrent eye-tracking and response latency assessment | Healthy controls | All participants had a direction bias (i.e., heightened attention capture) for food, specifically for high-calorie food. However, adults with AN subsequently avoided maintaining attention (i.e., had a decreased duration bias) to food versus non-food cues compared to controls. Adolescents with AN showed significantly increased attention maintenance on food stimuli |
| [47]        | N=56 patients with BN and BED | To examine if Approach Bias Modification (ABM) may reduce implicit bias to food (i.e., approach bias) as well as binge eating and related symptoms | ABM modification training vs. sham training | Sham condition | ABM tended to result in greater reductions in ED symptoms than sham ABM. Food intake, approach bias, and attention bias to food remained unaffected |
| [37]        | Patients with AN (N=63), and a comparison group of adolescents without eating pathology (N=57) | To investigate differences in patients with AN with regard to implicit vs. explicit biases towards food in two tasks applying food as task-irrelevant vs. relevant feature | Affective Simon Task and Stimulus Response Compatibility task | Healthy controls | Patients with AN showed a reduced implicit approach bias towards high-calorie food |
BN and healthy controls; Blechert et al. [51] examined explicit and implicit associations between shape/weight and the participants’ self-evaluation and found that both ED groups showed significantly more pronounced implicit bias than controls in terms of associating shape/weight concerns with self-evaluation domains [51].

Parling et al. [52] compared implicit pro-thin and anti-fat biases to the self and others in patients diagnosed with AN/subthreshold AN and healthy controls using the Implicit Relational Assessment Procedure (IRAP). The IRAP assesses hypothesized a priori established verbal relations (e.g., same or opposite) between sample (e.g., pleasant) and target cues (e.g., love). As in other tasks of this kind, faster responding is to be expected when same is required, indicating congruence between sample and target cue and, thus, a bias. The clinical cohort showed an implicit pro-fat bias to others and stronger anti-fat bias to the self compared to controls. These findings were related to the over-evaluation of weight and shape in the clinical group [52].

Patients with AN often have a distorted perception of their own body and show deficits in interoception and haptic perception; conflicts in visual and tactile integration might be the case. Case et al. [53] investigated mechanisms leading to body image distortion in AN using the size-weight illusion (SWI) that is based on the implicit premise that small objects are heavier than large objects (of the same weight). The authors found that patients with AN had a significantly lower SWI compared to controls, although they had no difficulties to discriminate weight. Because the SWI is impacted by visual appearance, this result was presented as evidence towards a disintegration of visual and proprioceptive input in AN, in terms that patients with AN rely less on visual input but more on proprioceptive information when it comes to judging weight [53].

Using an ineffectiveness induction procedure followed by an appearance-related word stem completion task as the indirect assessment of implicit bias, McFarlane et al. [54] tested the body displacement theory which claims that patients with EDs will project aversive feelings about themselves onto their body. Patients with EDs who were made to feel ineffective had indeed elevated implicit appearance/body concerns compared to unrestrained and restrained eaters in the control group who did not display similar effects [54].

In a small study, Watson et al. [55] examined reward for face and body cues of others and attention using eye-tracking techniques in weight-restored females with AN and controls [55]. While the two groups of participants were similar in ratings of attractiveness, the group with AN was less likely to look at women’s faces when the body was presented as well and less likely to look in the eye region when faces alone were presented.

Brauhardt et al. [56] performed a study with obese-only participants, obese patients with BED (OB/BED) and controls to investigate associations between implicit and explicit weight bias in these groups. Higher explicit weight bias was found in the OB/BED group compared to both the other groups. However, the OB/BED group and the control group showed an equally strong implicit weight bias in the IAT, while the obese-only participants did not [56].

Khan and Petroczi [57] applied computerized tests measuring subconscious normative Ideal Body Image (IBI), Personalized self-identification Body Image (PBI) associations and Food Preferences (FP). Patients with EDs showed significantly stronger bias to a thin body image and stronger self-identification with a thin body image compared to healthy women. No differences were found in preferences to food. This study demonstrated that implicit biases with regard to body image were more adequate to distinguish patients with ED than food-related tasks, therefore suggesting that body image is at the core of disordered eating psychopathology [57].

Biases to the own body were assessed using the Mental Motor Imagery Task (MMI) in the study by Purcell et al. [58]. Participants were asked to imagine making a movement along their body and then to actually perform the movement. The mental image of one’s own body (body schema) was evaluated comparing the time needed to perform the two actions. Purcell et al. demonstrated that participants with ED had a distorted body schema, implicitly assuming that sensitive to control body parts were larger than they actually were [58].

Finally, in a recent study using an IAT, Izquierdo et al. [59] found fat-phobic and non-fat-phobic patients with AN, as well as underweight restrictive eaters and healthy controls to all display implicit negative bias towards underweight models [59]. Korn et al. [60] also examined patients with AN who self-reported fear of gaining weight and patients who denied it, and found a disparity between explicit statements and results in an indirect bias assessment task (implicit conjoint analysis, CA) to be present in non-fat-phobic patients, thus providing evidence that an implicit drive for thinness might as well exist in patients with AN who explicitly deny fat phobia [60].

All studies presented in “Studies investigating implicit biases in clinical (ED) cohorts: body cues” are shown in Table 2.

Discussion

We carried out a systematic search of the literature and identified studies presenting implicit (automatic, rapid, non-verbal) biases to food and body cues in the context of EDs. Twenty-nine studies met the eligibility criteria
Table 2  The table displays current research findings with regard to indirect measures and implicit biases in the field of body-related cues in patients with eating disorders. For details please refer to the main text

| Publication | Participants | Purpose | Instruments (indirect measures) | Control group or condition | Main outcome |
|-------------|--------------|---------|---------------------------------|---------------------------|-------------|
| Implicit bias in clinical cohorts: body image | |
| [43]        | N=30 females with an ED (N=15 AN, N=15 BN) and N=30 female controls | To examine appetitive and aversive responses to food and body cues in patients with EDs | Acoustically elicited Startle Eyeblink Modulation (SEM) | Healthy controls | There were no significant differences between groups regarding responses to body cues |
| [50]        | N=35 females with restrictive AN and N=35 matched normal weight controls | To examine whether an ultra-thin ideal or negative bias for overweight might be the motivation behind pathological restriction in AN | modified Affective Priming Test | Healthy control group | Unlike the control group, patients with AN did not show a positive bias for the ultra-thin body shape. Patients showed a negative bias for overweight both on the implicit and explicit level |
| [55]        | N=11 females with weight-restored AN, N=11 female controls | To investigate the implicit reward value of social stimuli for AN-patients | Eye-tracking | Healthy controls | Results showed that the faces of other females elicit approach behavior in control females but not in weight-restored AN. Females with Weight-restored AN hyperscanned emaciated bodies but explicitly reported that underweight bodies were less attractive than normal-weight body cues |
| [54]        | N=33 restrained eaters, N=61 unrestrained eaters, N=26 patients with ED | To test the body displacement theory by means of an ineffectiveness induction procedure and a body dissatisfaction measure | Appearance-related Word Stem Completion Task | Non-clinical cohort (unrestrained and restrained eaters) as a control group, control condition with self-esteem conducive memories | Patients with EDs who were made to feel ineffective reported more implicit appearance/body concern than participants in both control conditions |
| [51]        | N=20 patients with AN, N=20 patients with BN, N=28 controls | To examine associations between weight/shape concerns and self-evaluation | Affective Priming paradigm | | Shape/weight concerns and self-evaluation were linked in the ED groups but not in controls |
| [52]        | N=17 females with AN, N=17 female controls | To compare weight-related beliefs in women with AN and sub-threshold AN versus healthy women, while at the same time exploring the relation between bias for oneself and for others | Implicit pro-thin and anti-fat bias towards self and others using the Implicit Relational Assessment Procedure (IRAP) | Healthy control group | Patients showed an implicit pro-fat bias for others, but stronger anti-fat bias for the self |
| [53]        | N=10 females with AN and N=10 healthy controls | To examine the mechanisms underlying body image distortion in AN | Size-Weight Illusion (SWI) | Healthy control group | Patients with AN exhibited a markedly reduced SWI relative to controls, even though their ability to discriminate weight was unaffected |
| [34]        | N=25 females with AN (N=9 with acute AN, N=14 recovered from AN), N=29 healthy control females | To assess responses towards overweight and underweight In patients with AN | AMP | Healthy control group and control group recovered from AN | Patients with AN showed significantly more negative implicit bias for overweight cues |
| Publication | Participants | Purpose | Instruments (indirect measures) | Control group or condition | Main outcome |
|-------------|--------------|---------|--------------------------------|---------------------------|--------------|
| [49]        | $N=30$ females with AN, $N=29$ healthy control females | To determine if patients with AN associate emaciation with beauty | Lexical Decision Task | Healthy control group | Females with AN had a stronger association between emaciation and beauty than control females. Further, ED symptoms were found to significantly predict the strength of the association between emaciation and beauty. Paradoxically, also the association between emaciation and ugliness was stronger in patients with AN than in controls |
| [56]        | $N=26$ obese patients with BED, $N=26$ obese-only participants, $N=26$ healthy norm weight controls | To examine explicit and implicit self-esteem in BED compared to an obese-only and a control group | self-esteem IAT | Healthy control group and group of obese without BED | Levels of implicit self-esteem were found to be lower in obese patients with BED, as well as in the obese-only group when compared to healthy control participants |
| [57]        | $N=53$ women with an ED (BN, AN, EDNOS), $N=41$ females at risk for an ED, $N=23$ healthy females | To assess bias to foods as well as self-esteem, levels of body dissatisfaction and body image perception in women with EDs compared to healthy controls | Computerized online tests assessing bias with regard to subconscious normative Ideal Body Image (IBI), Personalized self-identification Body Image (PBI) and Food Preferences (FP) using IATs and AAT | Healthy control group | Patients with ED showed significantly stronger biases for thin body images and stronger self-identification with thin body images compared to healthy females. No differences were found in food bias |
| [35]        | Patients with AN and BN ($N=92$) and controls ($N=85$) | To test if patients with EDs differ from controls in implicit biases to food and body cues and if these biases predict ED symptoms and behaviors over a 4-week period | AMP | Healthy controls | Patients with AN and BN showed a higher negative implicit bias to average body cues compared to controls |
| [58]        | $N=42$ inpatients with ED, $N=40$ healthy controls | To interrogate the body schema in patients with ED by assessing participants’ mental image of their body (i.e., body schema) | Implicit Mental Motor Imagery (MMI) task | Healthy controls | Participants with eating disorders consider themselves to be larger than they truly are |
| [39]        | $N=36$ women with ED, $N=36$ healthy controls | To assess the effect of transcranial direct current stimulation (tDCS) on implicit food- and body-related biases | IAT (body-pictures) | Healthy controls and sham-tDCS | tDCS on frontal and occipito-temporal cortices showed no effects with regard to body stimuli |
| [60]        | $N=30$ fat-phobic and $N=7$ non-fat-phobic women with AN, and $N=29$ healthy control women | To examine if explicit and implicit evaluations of weight gain are congruent | Conjoint Analysis (CA) | Healthy controls | Correlation between explicitly assessed drive for thinness and implicit CA score was low |
and were included in this review. We identified 16 eligible studies using food cues and 18 eligible studies with body cues. Despite the methodological heterogeneity and considering conflicting results, some main observations may be enunciated in an attempt to synthesize current findings and conclusions.

Differences between patients with EDs and healthy controls regarding implicit biases to food are found across studies. Repeated findings showed a lack of incentive salience to food (in terms of reduced bias to high-calorie food or food in general) in patients diagnosed with AN [36]. However, restrained eaters among healthy controls were found to display a bias to high-calorie food [14]. Such findings may have several implications. Despite the methodological heterogeneity between studies, they might explain the ability of patients with AN to explicitly control their food intake, although it is not clear, whether they describe predisposing vulnerability factors or disorder sequelae. Then, these findings may point towards different underlying mechanisms between patients with AN on the one side and attempts to restrict food intake in otherwise healthy controls on the other, although this assumption cannot provide inferences on aspects of cause/effect and needs to be further confirmed. Interestingly, healthy participants classified as high food cravers showed stronger approach bias to food [61], a finding that resembles findings in patients with BED [44]. The only study assessing the implicit bias to food in different stages of AN [40] showed that implicit bias to food in AN appears to be independent of weight status. In contrast to AN, implicit biases to food are understudied in BN. Disinhibited food intake in terms of binge eating might, however, be associated with implicit attentional biases to food in binge eaters [44]. It has also been suggested that implicit bias underlying binge eating episodes may not be captured adequately under laboratory conditions, thus outside the context of an actual bingeing episode [45].

Studies on implicit biases to body cues in patients with EDs also consistently show differences to controls. The available results suggest that the general pro-thin/anti-fat implicit bias previously found in IAT studies [19, 62] might be the result of pro-thin implicit bias to the self. As shown further above, there is also evidence that the underlying implicit bias that may negatively impact eating behaviors might be related to body image rather than to food per se [57], although this aspect requires replication. Surprisingly, studies in non-clinical populations have consistently shown implicit anti-fat and pro-thin bias in investigations with body cues [19]. Thus, in contrast to studies applying food cues, the approach bias to body cues seems to run in parallel in both healthy controls and cohorts with EDs. Furthermore, implicit bias to the thin ideal seems to be associated with the occurrence of ED-related symptomatology, and differences between non-clinical and clinical cohorts seem to lie

| Table 2 (continued) |
|---------------------|
| Publication | Participants | Purpose | Instruments (indirect measures) | Control group or condition |
| [48] | Study 1: foreign face on body avatar: N = 40 women with AN and N = 40 healthy women; study 2: own face on body avatar: N = 39 women with AN and N = 38 healthy women | To investigate implicit evaluations of thin and normal-weight bodies with and without identification with the respective body-avatar | AAT using a body avatar with a standard face or the participants' face | Healthy controls |
| [49] | N = 59 fat-phobic (FP) and N = 13 non-fat-phobic (NFP) women with AN, N = 10 women with avoidant/restrictive food intake disorder, N = 32 healthy controls | To assess possible differences in explicit and implicit biases between fat-phobic and non-fat-phobic AN women, as well as between AN and healthy controls | IAT using pro-dieting statements and body image-based IAT | Healthy controls |

FP- and NFP-AN displayed a positive bias to pro-dieting statements. In the body image-based IAT, all groups showed a negative bias to underweight models, although healthy controls displayed a significantly stronger negative bias than patients with FP-AN and NFP-AN.
in the grade of severity. Accordingly, ED-related symptoms were found to predict the strength of the implicit association between emaciation and beauty.

The variety in methodologies does not allow direct comparisons between studies, e.g., while in the study by Spring and Bulik [34], using the affect misattribution procedure, a negative bias only to high-calorie food was observed, indicating that patients with AN do not display negative implicit bias for all foods, other authors, using the approach avoidance task (e.g., [36]), found a negative implicit bias to food independent of calorie content. Thus, while differences in methodology do not permit generalization of results, the experimental paradigm per se might be considered to have an impact on the assessed bias. Similarly, the choice of body cues (emaciated, thin, normal weight, or overweight bodies) seems decisive for the identification of bias, and patients with AN hyperscan emaciated bodies while paying less attention to the face, as presented further above [55].

Implicit and explicit biases are capable of influencing behavior independently of each other [63]. Regarding food choice, a consistent and predictable relation between implicit and explicit biases and behavior remains inconclusive [64]. Some studies found relations between implicit—but not explicit—biases and spontaneous snack selections, while others found no such relation [64]. Implicit biases predict food choice when individuals have a low cognitive capacity (e.g., being distracted or emotional after watching an upsetting film) or when there is low inhibitory control (e.g., high levels of impulsivity) [11, 65, 66]. Low inhibitory control heightens the impact of implicit food biases on overeating [67–69] and is associated with the ingestion of higher amounts of high-calorie food [70, 71] the failure of diets [72], and even with obesity [70, 73–76]. Other authors found that implicit affective bias was a significant predictor of snack choice at low, but not high levels of ED symptomatology [76]. Given the prior inconsistencies in the strength of the relationship between implicit bias and spontaneous eating behavior [64], the study by [76] suggests that ED symptomatology may moderate the strength of the relation. Possibly, elevated self-control, as in some types of EDs, reduces the impact of implicit affective biases on behavior [77]. Overall, there is an ambiguity remaining. The study by Goldstein et al. [78] showed that neither implicit nor explicit biases alone predicted disinhibited eating and that there was no mediating effect of impulsivity on implicit biases to predict eating behavior [78]. This finding confirmed a previous study showing that implicit biases were poor predictors of actual behavior [79].

**Bias trainings**

On the behavioral level, implicit biases were a predictor of eating behavior at low levels of ED-related symptomatology. While treatment effects on implicit biases cannot be distinguished due to the lack of respective studies, there is limited evidence that biases are modifiable. This has led to the implementation of implicit bias trainings. Such trainings are up to now no established options for modifying eating habits or for the management of EDs. Prior to designing and providing implicit bias trainings, it is important to further examine the direction (approach vs. avoidance) as well as the specificity of bias (e.g., by testing disorder-related against neutral cues and involving healthy controls).

To facilitate behavioral modifications, research groups applied repeated response inhibition and were able to demonstrate reductions in the valence as well as the positive bias to cues [80–86]. Such interventions were mostly tested within the context of addictive behaviors and were proven effective, e.g., in modifying implicit approach biases to alcohol in patients with alcohol dependence [86]. These types of interventions to modify implicit biases may thus further diversify standard psychotherapeutic approaches.

It has been feasible to prompt individuals to eat less and/or healthier by training them to respond to temptations with an automatic inhibition movement [87–90]. Training of food-related inhibitory control appears to be especially effective for individuals with a strong urge to consume specific foods [81, 82, 87, 89]. In this sense, food-associated inhibitory control was practiced in a group of chocolate lovers who then consumed significantly less chocolate in an alleged taste test compared to participants who had not undergone the chocolate/no-go training [87]. Similarly, both implicit bias as well as craving for chocolate decreased following a training in which participants had to associate words of avoidance with chocolate pictures [91].

Preliminary evidence suggests that trainings using the AAT can modify implicit biases to food in healthy participants [92, 93]. Ferentzi et al. [94] trained obese participants to make avoidance movements in response to high-calorie, unhealthy food cues and approach movements in response to cues representing a healthy lifestyle, while a control group received sham training. The approach avoidance bias improved in the active training group compared to the control group, an effect that even generalized to novel, untrained food cues. No training impact was found on ED-related questionnaires or the BMI [94]. On the other hand, there are also studies failing to find effects. In the study by Becker et al. an AAT training in normal-weight individuals did not change the implicit bias to food, at least not following a single session [95]. Using a brief evaluative conditioning intervention, food intake was found to be malleable, but this effect was only observed among individuals with low inhibitory control [96]. Combined trainings of implicit bias modification and inhibition control seem to have an additional impact on implicit bias to unhealthy food: participants who were both trained to
indirectly avoid pictures of unhealthy food and to inhibit responses to them in a go/no-go task showed less implicit bias (liking) to food in an IAT, while each training condition alone did not alter implicit biases in this study. Training did not affect explicit food choice or intake [97].

There are also training studies of implicit bias to food in (sub)clinical cohorts, although only one recent study by [47] fulfilled the eligibility criteria of inclusion in this review (e.g., presence of a control condition) [47]. In a previous study by the same authors in participants with subclinical BN and high levels of self-reported food craving, indirect avoidance movements to visual food cues were practiced in ten 15-min sessions over a 5-week course. The authors examined the effect of training on craving, ED symptoms, and bias to food as well as a possible generalization to other biases (i.e., attentional bias to food cues). At baseline, participants showed approach and attentional bias to high-calorie food that were significantly reduced and turned into avoidance biases after the training. Participants also reported pronounced reductions in food craving and ED symptoms [98]. This study added to the evidence suggesting that effects of a training targeting one specific (cognitive) bias may generalize to another [99]. Boutelle et al. [100] trained females with binge eating behavior to focus their attention away from food cues by reinforcing attention to the neutral word of a presented word pair which included one food-related and one neutral word. Repeated training sessions at least twice a week over 12 weeks led to reduced binge episodes, decreased weight, BMI and ED symptoms [100]. These results provide evidence for distinct clinical effects of attentional bias modification trainings. Due to the lack of a control group, it remains unclear if this training improved executive control of attention in general. The long-term efficacy of such trainings is still unknown.

Apart from explicit mechanisms of cognitive modification and emotion regulation, novel implicit trainings conceived as add-ons to classical psychotherapy are important to develop. Reducing discrepancy around unhealthy foods could be accomplished by either minimizing positive implicit bias (e.g., through associative priming or evaluative conditioning) [64, 101] and/or by minimizing negative explicit bias (e.g., decreasing rigidity and designations of so-called “forbidden foods”). Interventions aiming at reducing impulsivity (e.g., through computerized inhibitory control trainings) may also reduce the likelihood of eating in the presence of unhealthy foods [81]. In the case of AN, for example, implicit mechanisms of self-regulation would aim at attenuating the inhibitory, executive prefrontal control in patients with AN including automatic, conditioned reaction patterns by modifying dysfunctional incentive structures (i.e., increasing the salience of food-related cues). The anticipated outcome would then be a cutback on avoidance behaviors and the buildup of a stance over approach behaviors.

**Limitations**

Several limitations should be considered when interpreting the results of the studies presented in this work. Relatively small samples sizes limit the generalizability of findings. Additional research is needed to clarify the replicability of implicit biases, due to the fact that most findings are singular, cross-sectional findings by different research groups. As most studies were cross-sectional, no conclusions about cause/effect can be drawn. Further longitudinal studies are necessary to examine the unique predictive validity of implicit vs. explicit bias on eating behaviors and in eating disorders. Finally, controlled bias modification (training) studies are still scarce. Only repeated and independent evaluations may avoid premature closure about the magnitudes of effects and potentially effective interventions. On the other hand, an overemphasis on repeating experiments could provide an unfounded sense of certainty when findings rely on a single approach. Multi-method approaches, including several indirect assessments of implicit bias are therefore needed. Finally, studies examining implicit biases to cues other than food or body cues (affect, learning, etc.) were excluded from this review, mostly due to the fact that single findings but no systematic investigations are published so far.

**Future directions**

There is a need for novel, neurobiologically founded strategies intervening on the implicit (pre-verbal) level in addition to classical psychotherapy. A psychotherapeutic treatment that only accounts for behavioral change by means of the conscious influence on the self (e.g., cognitive strategies) does not take into account that self-regulation may as well be generated through the implicit and automatic route of processing. This may explain why individuals are often not capable to steer their behavior according to their own set goals [8, 68]. As proposed by the dual-process theories, the slower and complex reflective processes are not able to take effect early enough, to impact upon automatically generated processes [102].

Specific interventions relating to relevant aspects of implicit self-regulation may diversify our current psychotherapeutic approaches to EDs. The aim would be to transform explicit regulation into a more implicit and resource-based process, going along with decreased drain of cognitive resources and thus increased odds of successful implementation of new behaviors [103, 104]. Neurofeedback arises as a procedure that may facilitate the explicit regulation of otherwise involuntary (implicit)
neural function [101, 105]. Frequent utilization of explicit strategies may, with time, automatize the initiation of more implicit processes. Implicit regulation mechanisms may be selectively targeted, e.g., in the form of training of automatic appraisals; a training of automatic appraisal was capable of influencing the interpretation bias in novel situations and strengthen the self-confidence of participants [106]. Technological innovations are likely to be instrumental in future empirical work to develop and evaluate effective trainings for appetitive behaviors [107]. Implicit bias trainings need to be further developed, standardized, delivered by skilled staff and continuously re-designed considering ongoing evidence-based practice. Future research may identify determinants of efficacy that may allow to choose an implicit bias intervention based on patients’ individual characteristics. Long-term efficacy is another serious challenge within this context.

- What is already known on this topic: Explicit and implicit biases towards food- and body-related cues have been found to differ between patients with eating disorders and healthy individuals. There have been attempts to therapeutically influence explicit and implicit biases.

- What this study adds: A systematic review on implicit response biases to food- and body-related cues in eating disorders.

Acknowledgements Open Access funding provided by Projekt DEAL. GP was supported by the Loretta Anne Rogers Chair in Eating Disorders Fund at University Health Network and the University of Toronto. SK has been funded by two grants from the German Science Foundation (DFG KU 3322/1-1, SFB 936/C7), the European Union (ERC-2016-SG-Self-Control-677804) and a Fellowship from the Jacobs Foundation (JRF 2016-2018).

Author contributions GP had the idea for the article, GP and ADS-H performed the literature search, screened and selected the studies to be included, GP and ADS-H wrote the article, and LMS and SK critically revised the work.

Funding There was no funding for this study.

Compliance with ethical standards Conflict of interest The authors declare that they have no conflict of interest.

Open Access This article is licensed under a Creative Commons Attribution 4.0 International License, which permits use, sharing, adaptation, distribution and reproduction in any medium or format, as long as you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons licence, and indicate if changes were made. The images or other third party material in this article are included in the article’s Creative Commons licence, unless indicated otherwise in a credit line to the material. If material is not included in the article’s Creative Commons licence and your intended use is not permitted by statutory regulation or exceeds the permitted use, you will need to obtain permission directly from the copyright holder. To view a copy of this licence, visit http://creativecommons.org/licenses/by/4.0/.

References

1. Bargh JA (1994) The Four Horsemen of automaticity: awareness, efficiency, intention, and control in social cognition. In: Wyer RS, Srull TK (eds) Handbook of social cognition. Erlbaum, Hillsdale, pp 1–40

2. Alonso-Alonso M, Pascual-Leone A (2007) The right brain hypothesis for obesity. JAMA 297(16):1819–1822. https://doi.org/10.1001/jama.297.16.18193

3. Howard GS (1980) Response-shift bias: a problem in evaluating interventions with pre/post self-reports. Eval Rev 4(1):93–106. https://doi.org/10.1177/0193841X8000400105

4. Sprangers M, Hoogstraten J (1989) Pretesting effects in retrospective pretest-posttest designs. J Appl Psychol 74:265–272. https://doi.org/10.1037/0021-9010.74.2.265

5. Conroy MB, Yang K, Elci OU, Gabriel KP, Styn MA, Wang J, Kriska AM, Sereika SM, Burke LE (2011) Physical activity self-monitoring and weight loss: 6-month results of the SMART Trial. Med Sci Sports Exerc 43:1568–1574. https://doi.org/10.1245/MSS.0b013e3182b93925

6. Kahneman D (2011) Thinking, fast and slow. Macmillan, New York

7. Lindgren KP, Neighbors C, Teachman BA, Wiers RW, Westgate E, Greenwald AG (2013) I drink therefore I am: validating alcohol-related implicit association tests. Psychol Addict Behav 27:1–13. https://doi.org/10.1037/a0027640

8. Strack F, Deutsch R (2004) Reflective and impulsive determinants of social behavior. Pers Soc Psychol Rev 8:220–247. https://doi.org/10.1207/s15327957pspr0803_1

9. Job V, Oertig D, Brandstätter V, Allemand M (2010) Discrepancies between implicit and explicit motivation and unhealthy eating behavior. J Pers 78:1209–1238. https://doi.org/10.1111/j.1264-6999.2010.00648.x

10. Petty RE, Brînol P, DeMarree KG (2007) The Meta-Cognitive Model (MCM) of attitudes: implications for attitude measurement, change, and strength. Soc Cogn 25:657–686. https://doi.org/10.1521/soco.2007.25.5.657

11. Friese M, Hofmann W, Wänke M (2008) When impulses take over: Moderated predictive validity of explicit and implicit attitude measures in predicting food choice and consumption behaviour. Br J Soc Psychol 47:397–419. https://doi.org/10.1348/014466607X241540

12. Hoefling A, Strack F (2008) The tempting effect of forbidden foods. High calorie content evokes conflicting implicit and explicit evaluations in restrained eaters. Appetite 51:681–689. https://doi.org/10.1016/j.appet.2008.06.004

13. Veenstra EM, de Jong PJ (2010) Restrained eaters show enhanced automatic approach tendencies towards food. Appetite 55:30–36. https://doi.org/10.1016/j.appet.2010.03.007

14. Houben K, Roefs A, Jansen A (2010) Guilty pleasures. Implicit preferences for high calorie food in restrained eating. Appetite 55:18–24. https://doi.org/10.1016/j.appet.2010.03.003

15. DelParigi A, Chen K, Salie AD, Hill JO, Wing RR, Reiman EM, Tataranni PA (2007) Successful dieters have increased neural activity in cortical areas involved in the control of behavior. Int J Obes 31:440–448. https://doi.org/10.1038/sj.ijo.0803431

16. Demos KE, Kelley WM, Heatherton TF (2010) Dietary restraint violations influence reward responses in nucleus accumbens.
and amygdala. J Cogn Neurosci 23:1952–1963. https://doi.org/10.1162/jocn.2010.21568
17. Bongers P, Jansen A, Houben K, Roefs A (2013) Happy eating: the Single Target Implicit Association Test predicts overeating after positive emotions. Eat Behav 14:348–355. https://doi.org/10.1016/j.eatbeh.2013.06.007
18. Conner MT, Perugini M, O’Gorman R, Ayres K, Prestwich A (2007) Relations between implicit and explicit measures of attitudes and measures of behavior: evidence of moderation by individual difference variables. Pers Soc Psychol Bull 33(12):1727–1740. https://doi.org/10.1177/0146167207309194
19. Schwartz MB, Vartanian LR, Nosek BA, Brownell KD (2006) The Influence of one’s own body weight on implicit and explicit anti-fat bias. Obesity 14:440–447. https://doi.org/10.1038/oby.2006.58
20. Woud ML, Anschutz DJ, Van Strien T, Becker ES (2011) Measuring thinspiration and fear of fat indirectly. A matter of approach and avoidance. Appetite 56:451–455. https://doi.org/10.1016/j.appet.2010.12.012
21. Ahern A, Bennett KM, Hetherington M (2008) Internalization of the ultra-thin ideal: positive implicit associations with underweight fashion models are associated with drive for thinness in young women. Eat Disord 16(4):294–307. https://doi.org/10.1080/10603309.2011.593163
22. Jurascio AS, Forman EM, Timko CA, Herbert JD, Butryn M, Lowe M (2011) Implicit internalization of the thin ideal as a predictor of increases in weight, body dissatisfaction, and disordered eating. Eat Behav 12:207–213. https://doi.org/10.1016/j.eatbeh.2011.04.004
23. Martinelli MK, Holzinger JB, Chasson GS (2014) Validation of an interpretation bias assessment for body dissatisfaction. Body Image 11:557–561. https://doi.org/10.1016/j.bodyim.2014.08.010
24. Misener K, Libben M (2017) Risk for eating disorders mediates interpretation bias in a semantic priming task. Body Image 21:103–106. https://doi.org/10.1016/j.bodyim.2017.03.004
25. Seibt B, Häfner M, Deutsch R (2007) Prepared to eat: how immediate affective and motivational responses to food cues are influenced by food deprivation. Eur J Soc Psychol 37:359–379. https://doi.org/10.1002/ejsp.365
26. Pinel JPJ, Assanand S, Lehman DR (2000) Hunger, eating, and ill health. Am Psychol 55:1105–1116. https://doi.org/10.1037/0003-066X.55.11.1005
27. Epstein LH, Salvy SJ, Carr KA, Dearing KK, Bickel WK (2010) Food reinforcement, delay discounting and obesity. Physiol Behav 100:438–445. https://doi.org/10.1016/j.physbeh.2010.04.029
28. Heatherton TF, Wagner DD (2011) Cognitive neuroscience of self-regulation failure. Trends Cogn Sci 15:132–139. https://doi.org/10.1016/j.tics.2010.12.005
29. Ralph-Nearman C, Achee M, Lapidus S, Stewart JL, Filik R (2019) A systematic and methodological review of attentional biases in eating disorders: Food, body, and perfectionism. Brain Behav 9:e01458. https://doi.org/10.1002/brb3.1458
30. Moher D, Liberati A, Tetzlaff J, Altman DG (2009) PRISMA 2009 flow diagram. PRISMA Statement 6:1371
31. Greenland AG, McGhee DE, Schwartz JL (1998) Measuring individual differences in implicit cognition: the implicit association test. J Pers Soc Psychol 74:1464
32. Rinck M, Becker ES (2007) Approach and avoidance in fear of spiders. J Behav Ther Exp Psychiatry 38:105–120. https://doi.org/10.1016/j.jbtep.2006.10.001
33. Roefs A, Stapert D, Isabella LAS, Wolters G, Wojciechowski F, Jansen A (2005) Early associations with food in anorexia nervosa patients and obese people assessed in the affective priming paradigm. Eat Behav 6:151–163. https://doi.org/10.1016/j.eatbeh.2004.10.001
34. Spring VL, Bulik CM (2014) Implicit and explicit affect toward food and weight stimuli in anorexia nervosa. Eat Behav 15:91–94. https://doi.org/10.1016/j.eatbeh.2013.10.017
35. Smith AR, Forrest LN, Velkoff EA, Ribeiro JD, Franklin J (2018) Implicit attitudes toward eating stimuli differentiate eating disorder and non-eating disorder groups and predict eating disorder behaviors. Int J Eat Disord 51:343–351. https://doi.org/10.1002/eat.22843
36. Paslakis G, Kühn S, Schaubschläger A, Schieber K, Röder K, Rauh E, Erim Y (2016) Explicit and implicit approach vs. avoidance tendencies towards high vs. low calorie food cues in patients with anorexia nervosa and healthy controls. Appetite 107:171–179. https://doi.org/10.1016/j.appet.2016.08.001
37. Neimeijer RAM, Roefs A, Glasbouwer KA, Jonker NC, de Jong PJ (2019) Reduced automatic approach tendencies towards task-relevant and task-irrelevant food pictures in Anorexia Nervosa. J Behav Ther Exp Psychiatry 65:101496. https://doi.org/10.1016/j.jbtep.2019.101496
38. Soussignan R, Jiang T, Rigaud D, Royet JP, Schaal B (2010) Subliminal fear priming potentiates negative facial reactions to food pictures in women with anorexia nervosa. Psychol Med 40:503–514. https://doi.org/10.1017/S0033291709999377
39. Mattavelli G, Gallucci A, Schiena G, D’Agostino A, Sassetti T, Bonora S, Bertelli S, Benetti A, Tognoli E, Ruggiero GM, Sassaroli S, Romero Lauro L, Gamboni O, Papagno C (2019) Transcranial direct current stimulation modulates implicit attitudes towards food in eating disorders. Int J Eat Disord 52:576–581. https://doi.org/10.1002/eat.23046
40. Cowdrey FA, Finlayson G, Park RJ (2013) Liking compared with wanting for high- and low-calorie foods in anorexia nervosa: aberrant food reward even after weight restoration. Am J Clin Nutr 97:463–470. https://doi.org/10.3945/ajcn.112.046011
41. Werthmann J, Simic M, Konstantellou A, Mansfield P, Mercado D, van Ens W, Schmidt U (2019) Same, same but different: Attention bias for food cues in adults and adolescents with anorexia nervosa. Int J Eat Disord 52:681–690. https://doi.org/10.1002/eat.23064
42. Hermans D, Pieters G, Eelen P (1998) Implicit and explicit memory for shape, body weight, and food-related words in patients with anorexia nervosa and nondieting controls. J Abnorm Psychol 107:193–202. https://doi.org/10.1037/0021-843X.107.2.193
43. Friedrich H-C, Kumari V, Uher R, Riga M, Schmidt U, Campbell IC, Herzog W, Treasure J (2006) Differential motivational responses to food and pleasurable cues in anorexia and bulimia nervosa: a startle reflex paradigm. Psychol Med 36:1327–1335. https://doi.org/10.1017/S0033291706008129
44. Deluchi M, Costa FS, Friedman R, Goncalves R, Bizarro L (2017) Attentional bias to unhealthy food in individuals with severe obesity and binge eating. Appetite 108:471–476. https://doi.org/10.1016/j.appet.2016.11.012
45. Paslakis G, Kühn S, Grunert S, Erim Y (2017) Explicit and implicit approach vs. avoidance tendencies towards high vs. low calorie food cues in patients with obesity and active binge eating disorder. Nutrients 9:1068. https://doi.org/10.3390/nu9101068
46. Leebr J, Schag K, Brinkmann A, Ehlis AC, Fallgatter AJ, Zipfel S, Giel KE, Dresler T (2016) Alleged approach-avoidance conflict for food stimuli in binge eating disorder. PLoS ONE 11:e0152271. https://doi.org/10.1371/journal.pone.0152271
47. Brockmeyer T, Friederich H-C, Küppers C, Chowdhury S, Harms L, Simmonds J, Gordon G, Potterrion R, Schmidt U (2019) Approach bias modification training in bulimia nervosa and binge-eating disorder: a pilot randomized controlled trial. Int J Eat Disord 52:520–529. https://doi.org/10.1002/eat.23024
48. Brockmeyer T, Burdenski K, Anderle A, Voges MM, Vocks S, Schmidt H, Wünsch-Leiteritz W, Leiteritz A, Friederich H-C (2020) Approach and avoidance bias for thin-ideal and normal-weight body shapes in anorexia nervosa. Eur Eat Disord Rev. https://doi.org/10.1002/erv.2744

49. Smith AR, Joiner TE Jr, Dodd DR (2014) Examining implicit attitudes toward emaciation and thinness in anorexia nervosa. Int J Eat Disord 47:138–147. https://doi.org/10.1002/eat.22210

50. Cserjesi R, Vermeulen N, Luminet O, Marechal C, Nef F, Simon Y, Lénárd L (2010) Explicit vs. implicit body image evaluation in restrictive anorexia nervosa. Psychiatry Res 175:148–153. https://doi.org/10.1016/j.psychres.2009.07.002

51. Blechert J, Ansorge U, Beckmann S, Tuschen-Caffier B (2011) The undue influence of shape and weight on self-evaluation in anorexia nervosa, bulimia nervosa and restrained eaters: a combined ERP and behavioral study. Psychol Med 41:185–194. https://doi.org/10.1017/S0033291710000395

52. Parling T, Cernvall M, Stewart I, Barnes-Holmes D, Ghaderi A (2012) Using the implicit relational assessment procedure to compare implicit pro-thin/anti-fat attitudes of patients with anorexia nervosa and non-clinical controls. Eat Disord 20(2):127–143. https://doi.org/10.1080/10640266.2012.654056

53. Case LK, Wilson RC, Ramachandran VS (2012) Diminished size-weight illusion in anorexia nervosa: evidence for visuo-proprioceptive integration deficit. Exp Brain Res 217:79–87. https://doi.org/10.1007/s00221-011-2974-7

54. McFarlane T, Urbszat D, Olmsted MP (2011) “I Feel Fat”: an experimental induction of body displacement in disordered eating. Behav Res Ther 49:289–293. https://doi.org/10.1016/j.brat.2011.01.008

55. Watson KK, Welring DM, Zucker N, Platt M (2010) Altered social reward and attention in anorexia nervosa. Front Psychol. https://doi.org/10.3389/fpsyg.2010.00036

56. Brauhardt A, Rudolph A, Hilbert A (2014) Implicit cognitive processes in binge-eating disorder and obesity. J Behav Ther Exp Psychiatry 45:285–290. https://doi.org/10.1016/j.bjtep.2014.01.001

57. Khan S, Petróczí A (2015) Stimulus-response compatibility tests of implicit preference for food and body image to identify people at risk for disordered eating: a validation study. Eat Behav 16:54–63. https://doi.org/10.1016/j.eatbeh.2014.10.015

58. Purcell JB, Winter SR, Breslin CM, White NC, Lowe MR, Coslett HB (2018) Implicit mental motor imagery task demonstrates a distortion of the body schema in patients with eating disorders. J Int Neuropsychol Soc 24:715–723. https://doi.org/10.1017/S1355617718000371

59. Izquierdo A, Plessow F, Becker KR, Mancuso CJ, Slattery M, Murray HB, Hartmann AS, Misra M, Lawson EA, Eddy KT, Thomas JI (2019) Implicit attitudes toward eating and thinness distinguish fat-phobic and non-fat-phobic anorexia nervosa from avoidant/restrictive food intake disorder in adolescents. Int J Eat Disord 52:419–427. https://doi.org/10.1002/eat.22981

60. Korn J, Vocks S, Rollins LH, Thomas JI, Hartmann AS (2020) Fat-phobic and non-fat-phobic anorexia nervosa: a conjoint analysis on the importance of shape and weight. Front Psychol. https://doi.org/10.3389/fpsyg.2020.00090

61. Brockmeyer T, Hahn C, Reetz C, Schmidt H, Friederich H-C (2015) Approach bias and cue reactivity towards food in people with high versus low levels of food craving. Appetite 95:197–202. https://doi.org/10.1016/j.appet.2015.07.013

62. Vartanian LR, Peter Herman C, Polivy J (2005) Implicit and explicit attitudes toward fatness and thinness: the role of the internalization of societal standards. Body Image 2:373–381. https://doi.org/10.1016/j.bodyim.2005.08.002

63. Gawronski B, Bodenhausen GV (2006) Associative and propositional processes in evaluation: an integrative review of implicit and explicit attitude change. Psychol Bull 132:692–731. https://doi.org/10.1037/0033-2909.132.5.692

64. Ayres K, Conner MT, Prestwich A, Smith P (2012) Do implicit measures of attitudes incrementally predict snacking behaviour over explicit affect-related measures? Appetite 58:835–841. https://doi.org/10.1016/j.appet.2012.01.019

65. Eschenbeck H, Heim-Dreger U, Steinhlber A, Kohlmann C-W (2016) Self-regulation of healthy nutrition: automatic and controlled processes. BMC Psychol 4:4. https://doi.org/10.1186/s40359-016-0108-5

66. Wang Y, Zhu J, Hu Y, Fang Y, Wang G, Cui X, Wang L (2016) The effect of implicit preferences on food consumption: moderating role of ego depletion and impulsivity. Front Psychol. https://doi.org/10.3389/fpsyg.2016.01699

67. Hofmann W, Friese M (2008) Impulses got the better of me: Alcohol moderates the influence of implicit attitudes toward food cues on eating behavior. J Abnorm Psychol 117:420–427. https://doi.org/10.1037/0021-843X.117.2.420

68. Hofmann W, Friese M, Wiers RW (2008) Impulsive versus reflective influences on health behavior: a theoretical framework and empirical review. Health Psychol Rev 2:111–137. https://doi.org/10.1080/17437190802617668

69. Yeomans MR, Leitch M, Mobini S (2008) Impulsivity is associated with the disinhibition but not restraint factor from the Three Factor Eating Questionnaire. Appetite 50:469–476. https://doi.org/10.1016/j.appet.2007.10.002

70. Guerriero R, Nederkoorn C, Jansen A (2008) The interaction between impulsivity and a varied food environment: its influence on food intake and overweight. Int J Obes 32:708–714. https://doi.org/10.1038/sj.ijo.0803770

71. Guerriero R, Nederkoorn C, Stankiewicz K, Alberts H, Geschwind N, Martijn C, Jansen A (2007) The influence of trait and induced state impulsivity on food intake in normal-weight healthy women. Appetite 49:66–73. https://doi.org/10.1016/j.appet.2006.11.008

72. Jansen A, Nederkoorn C, van Baak L, Keirse C, Guerriero R, Havermans R (2009) High-restrained eaters only overeat when they are also impulsive. Behav Res Ther 47:105–110. https://doi.org/10.1016/j.brat.2008.10.016

73. Nederkoorn C, Guerriero R, Havermans R (2009) The interactive effect of hunger and impulsivity on food intake and purchase in a virtual supermarket. Int J Obes 33:905–912. https://doi.org/10.1038/sj.ijo.0803870

74. Guerriero R, Nederkoorn C, Schrooten M, Martijn C, Jansen A (2009) Inducing impulsivity leads high and low restrained eaters into overeating, whereas current dieters stick to their diet. Appetite 53:93–100. https://doi.org/10.1016/j.appet.2009.05.013

75. Nederkoorn C, Jansen E, Mulkins S, Jansen A (2007) Impulsivity predicts treatment outcome in obese children. Behav Res Ther 45:1071–1075. https://doi.org/10.1016/j.brat.2006.05.009

76. Ellis EM, Kiviniemi MT, Cook-Cottone C (2014) Implicit affective associations predict snack choice for those with low, but not high levels of eating disorder symptomatology. Appetite 77:124–132. https://doi.org/10.1016/j.appet.2014.03.003

77. Friese M, Hofmann W (2009) Control me or I will control you: Impulses, trait self-control, and the guidance of behavior. J Res Pers 43:795–805. https://doi.org/10.1016/j.jrp.2009.07.004

78. Goldstein SP, Forman EM, Meiran N, Herbert JD, Juarascio AS, Butryn ML (2014) The discrepancy between implicit and explicit attitudes in predicting disinhibited eating. Eat Behav 15:164–170. https://doi.org/10.1016/j.eatbeh.2013.10.021

79. Oswald FL, Mitchell G, Blanton H, Jaccard J, Tetlock PE (2013) Predicting ethnic and racial discrimination: a meta-analysis of IAT criterion studies. J Pers Soc Psychol 105:171–192. https://doi.org/10.1037/a0032734
80. Eberl C, Wiers RW, Pawelczack S, Rinck M, Becker ES, Lindemeyer J (2013) Approach bias modification in alcohol dependence: Do clinical effects replicate and for whom does it work best? Dev Cogn Neurosci 4:38–51. https://doi.org/10.1016/j.dcn.2012.11.002
81. Houben K, Jansen A (2011) Training inhibitory control. A recipe for resisting sweet temptations. Appetite 56:345–349. https://doi.org/10.1016/j.appet.2010.12.017
82. Houben K, Nederkoorn C, Wiers RW, Jansen A (2011) Resisting temptation: Decreasing alcohol-related affect and drinking behavior by training response inhibition. Drug Alcohol Depend 116:132–136. https://doi.org/10.1016/j.drugalcdep.2010.12.011
83. Veling H, Aarts H, Stroebe W (2013) Stop signals decrease choices for palatable foods through decreased food evaluation. Front Psychol. https://doi.org/10.3389/fpsyg.2013.00875
84. Veling H, Aarts H, Stroebe W (2013) Using stop signals to reduce impulsive choices for palatable unhealthy foods. Br J Health Psychol 18:354–368. https://doi.org/10.1111/bjhf.2014.282.12.002.x
85. Wiers RW, Eberl C, Rinck M, Becker ES, Lindemeyer J (2011) Retraining automatic action tendencies changes alcoholic patients’ approach bias for alcohol and improves treatment outcome. Psychol Sci 22(4):490–497. https://doi.org/10.1177/0956797611400615
86. Wiers RW, Gladwin TE, Rinck M (2013) Should we train alcohol-dependent patients to avoid alcohol? Front Psychiatry. https://doi.org/10.3389/fpsyt.2013.00303
87. Adams RC, Lawrence NS, Verbruggen F, Chambers CD (2017) Training response inhibition to reduce food consumption: mechanisms, stimulus specificity and appropriate training protocols. Appetite 109:11–23. https://doi.org/10.1016/j.appet.2016.11.014
88. Forman EM, Shaw JA, Goldstein SP, Butryn ML, Martin LM, Meaney N, Crosby RD, Manasse SM (2016) Mindful decision making and inhibitory control training as complementary means to decrease snack consumption. Appetite 103:176–183. https://doi.org/10.1016/j.appet.2016.04.014
89. Jones A, Di Lemma LCG, Robinson E, Christiansen P, Nolan S, Tudor-Smith C, Fiedl M (2016) Inhibitory control training for appetitive behaviour change: a meta-analytic investigation of mechanisms of action and moderators of effectiveness. Appetite 97:16–28. https://doi.org/10.1016/j.appet.2015.11.013
90. Sice E, Yokum S, Veling H, Kemps E, Lawrence NS (2017) Pilot test of a novel food response and attention training treatment for obesity: Brain imaging data suggest actions shape valuation. Behav Res Ther 94:60–70. https://doi.org/10.1016/j.brat.2017.04.007
91. Kemps E, Tiggesmann M, Martin R, Elliott M (2013) Implicit approach–avoidance associations for craved food cues. J Exp Psychol 19:30–38. https://doi.org/10.1037/a0031626
92. Fishbach A, Shah JY (2006) Self-control in action: Implicit dispositions toward goals and away from temptations. J Pers Soc Psychol 90:820–832. https://doi.org/10.1037/0022-3514.90.5.820
93. Schumacher SE, Kemps E, Tiggesmann M (2016) Bias modification training can alter approach bias and chocolate consumption. Appetite 96:219–224. https://doi.org/10.1016/j.appet.2015.09.014
94. Ferentz H, Scheibner H, Wiers R, Becker ES, Lindemeyer J, Beisel S, Rinck M (2018) Retraining of automatic action tendencies in individuals with obesity: a randomized controlled trial. Appetite 126:66–72. https://doi.org/10.1016/j.appet.2018.03.016
95. Becker D, Jostmann NB, Wiers RW, Holland RW (2015) Approach avoidance training in the eating domain: testing the effectiveness across three single session studies. Appetite 85:58–65. https://doi.org/10.1016/j.appet.2014.11.017
96. Haynes A, Kemps E, Moffitt R (2015) The moderating role of state inhibitory control in the effect of evaluative conditioning on temptation and unhealthy snacking. Physiol Behav 152:135–142. https://doi.org/10.1016/j.physbeh.2015.09.020
97. Kakoschke N, Kemps E, Tiggemann M (2017) The effect of combined avoidance and control training on implicit food evaluation and choice. J Behav Ther Exp Psychiatry 55:99–105. https://doi.org/10.1016/j.jbtep.2017.01.002
98. Brockmeyer T, Hahn C, Reetz C, Schmidt U, Friederich H-C (2015) Approach bias modification in food craving—a proof-of-concept study. Eur Eat Disord Rev 23:352–360. https://doi.org/10.1002/erv.2382
99. Amir N, Weber G, Beard C, Bomyea J, Taylor CT (2008) The effect of a single-session attention modification program on response to a public-speaking challenge in socially anxious individuals. J Abnorm Psychol 117:860–868. https://doi.org/10.1037/a0013445
100. Boutelle KN, Monreal T, Strong DR, Amir N (2016) An open trial evaluating an attention bias modification program for overweight adults who binge eat. J Behav Ther Exp Psychiatry 52:138–146. https://doi.org/10.1016/j.jbtep.2016.04.005
101. Schardt DM, Erik S, Nüsse C, Nöthen MM, Cichon S, Rietschel M, Treutlein J, Goschke T, Walter H (2010) Volition diminishes genetically mediated amygdala hyperreactivity. NeuroImage 53:943–951. https://doi.org/10.1016/j.neuroimage.2009.11.078
102. Gladwin TE, Fijger B, Crane EA, Wiers RW (2011) Addiction, adolescence, and the integration of control and motivation. Dev Cogn Neurosci 1:364–376. https://doi.org/10.1016/j.dcn.2011.06.008
103. Baumeister RF (2014) Self-regulation, ego depletion, and inhibition. Neuropsychologia 65:313–319. https://doi.org/10.1016/j.neuropsychologia.2014.08.012
104. Vohs KD, Heatherton TF (2000) Self-regulatory failure: a resource-depletion approach. Psychol Sci 11(3):249–254. https://doi.org/10.1111/1467-9280.00250
105. Thibault RT, Lifshitz M, Birbaumer N, Raz A (2015) Neurofeedback, self-regulation, and brain imaging: clinical science and fad in the service of mental disorders. PPS 84:193–207. https://doi.org/10.1159/000371714
106. Tran TB, Matthias Siemer M, Joormann J (2011) Implicit interpretation biases affect emotional vulnerability: a training study. Cogn Emot 25(3):546–558. https://doi.org/10.1080/02699931.2010.532393
107. Forman EM, Goldstein SP, Flack D, Evans BC, Manasse SM, Dochat C (2018) Promising technological innovations in cognitive training to treat eating-related behavior. Appetite 124:68–77. https://doi.org/10.1016/j.appet.2017.04.011

Publisher’s Note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.