Techniques for Modifying Impulsive Processes Associated with Unhealthy Eating: A Systematic Review

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Abstract

Objective: This systematic review aimed to; (i) identify and categorize techniques used to modify or manage impulsive processes associated with unhealthy eating behavior, (ii) describe the mechanisms targeted by such techniques and (iii) summarize available evidence on the effectiveness of these techniques.

Methods: Searches of 5 bibliographic databases identified studies, published in English since 1993, that evaluated at least one technique to modify impulsive processes affecting eating in adults. Data were systematically extracted on study characteristics, population, study quality, intervention techniques, proposed mechanisms of action and outcomes. Effectiveness evidence was systematically collated and described without meta-analysis.

Results: Ninety-two studies evaluated 17 distinct impulse management techniques. They were categorized according to whether they aimed to (1) modify the strength of impulses, or (2) engage the reflective system or other resources in identifying, suppressing or otherwise managing impulses. Although higher quality evidence is needed to draw definitive conclusions, promising changes in unhealthy food consumption and food cravings were observed for visuospatial loading, physical activity, and if-then planning, typically for up to 1-day follow-up.

Conclusions: A wide range of techniques have been evaluated and some show promise for use in weight management interventions. However, larger-scale, more methodologically-robust, community based studies with longer follow-up times are needed to establish whether such techniques can have a long-term impact on eating patterns.

Keywords: Systematic review, eating behavior, dual-process models, impulsive processes, behavior change

Techniques for Modifying Impulsive Processes Associated with Unhealthy Eating: A Systematic Review

Managing obesity is a public health priority worldwide. This is a critical field of research because the risk of obesity-related health problems can be substantially reduced with weight loss of as little as 5% (Jensen et al., 2014; Paulweber et al., 2010). Systematic reviews have shown that interventions aiming to generate daily energy deficits can result in clinically meaningful weight loss (at least 2-3kg) in the short term (Greaves et al., 2011). Traditional weight loss interventions tend to target deliberative control strategies, such as bolstering motivation (through changes in beliefs, attitudes and intentions) and action planning. Yet, even when strong intentions are established, people often struggle to lose weight or maintain change over time (e.g., Elfhag & Rössner, 2005; Jeffery et al., 2000; Mann et al., 2007). This limited success may, in part, be due to the operation of non-deliberative processes that can override intentions in the moment-to-moment regulation of eating (Wansink & Sobal, 2007).

A series of dual-process models propose that in addition to conscious deliberative control of action, automatic or impulsive processes shape our everyday behavior patterns (Borland, 2014; Kahneman, 2011; Hall & Fong, 2007; Strack & Deutsch, 2004). These models describe how patterns of behavior, including eating, can be initiated by external cues with little conscious deliberation or monitoring. Such "mindless eating" (Wansink, 2007) can become independent of deliberative control such that behavior is regulated by cued impulses rather than current intentions. Consequently, identifying change techniques that can help people to control impulsively-regulated behavior is a key challenge for the science of health behavior change and for the design of effective weight-loss interventions (Friese, Hofmann, & Wiers, 2011; Hofmann, Friese, & Wiers, 2008; Kessler, 2009; Metcalfe & Mischel, 1999).

The Reflective Impulsive Model (RIM; Strack & Deutsch, 2004), the Context, Executive and Operating Systems model (CEOC; Borland, 2014), and Temporal Self-

Regulation Theory (TST; Hall & Fong, 2007) describe two distinct systems that regulate behavior. The "impulsive" (RIM) or "operational" (CEOS) system functions automatically, leading to "prepotent responses" (TST). Progressive activation of neuronal clusters link perceptions, reward anticipation, and learned motor responses to generate established behavior patterns with little conscious monitoring by the "reflective" (RIM) or "executive" (CEOS & TST) system. In contrast, the reflective or executive system incorporates reasoned attitudes, intentions and decision making, and requires cognitive resources to operate. This system runs in parallel and it is possible for (a) eating impulses to be recognized by the reflective system (we are often aware of our urges) and (b) the reflective system to override our impulses in some circumstances (we can sometimes resist temptation). We will use the term "impulsive process" to mean a regulatory process that can (but does not always) operate outside awareness of the reflective system, and we will use the term "urge" or "craving" to refer to awareness of such processes, within the reflective system.

People tend to be attracted to foods that are high in fat, salt and sugar (Kessler, 2009; Birch, 1999) and as eating responses are established over time, food cues can automatically trigger impulsive processes through the activation of hedonic reward based motivations and habitual behavioral routines associated with tempting stimuli (Papies, Stroebe, & Aarts, 2007; Hofmann et al., 2008). Such activation can result in mindless eating, including unhealthy food choices and overeating (e.g., Guerrieri, Nederkoorn, & Jansen, 2012).

The Elaborated Intrusion theory of Desire proposes that automatically activated hedonic motivations (as above) are followed by reflective cognitive elaborations which are experienced as conscious urges or cravings. These cognitive elaborations increase the desire to indulge in the temptation (Kavanagh, Andrade, & May, 2005; May, Andrade, Kavanagh, & Hetherington, 2012). Within the addiction literature, such cravings are identified as a major contributor to relapse (Franken, 2003). In eating behavior research, food cravings have been

linked to overeating (Nederkoorn, Smulders, Havermans, & Jansen, 2004; Nederkoorn, Smulders, & Jansen, 2000) and tend to involve energy dense foods rather than foods that are consistent with long-term healthy eating goals (Weingarten & Elston, 1991).

There is a growing interest in both addiction and eating research in identifying techniques that can prevent, or modify such impulsive processes (Dean, 2013; Hofmann, Friese, & Strack, 2009; Marteau, Hollands, & Fletcher, 2012; Sheeran, Gollwitzer, & Bargh, 2013). Indeed, a scoping review of "choice architecture" (Thaler & Sunstein, 2008) interventions has identified a range of techniques that alter micro-environments to "nudge" people towards making healthier choices in relation to dietary behaviors, physical activity, or the use of alcohol or tobacco. For example, Papies and Hamstra (2010) used subtle diet reminders on a restaurant menu in a field study which increased healthy food choices compared to a menu presenting specials. Public choice architecture interventions targeting multiple individuals simultaneously have already been reviewed (e.g., Hollands et al., 2013; Skov, Lourenço, Hansen, Mikkelsen, & Schofield, 2013). There is, however, no systematic overview of change techniques that directly target the individual to influence impulsive processes and their effectiveness specifically in the domain of eating behavior.

This review therefore aimed to; (i) identify and categorize the range of individual-level change techniques that have been used to modify or manage impulsive processes associated with unhealthy eating behavior, (ii) describe the mechanisms targeted by such techniques, and (iii) summarize available evidence on the effectiveness of these techniques.

Methods

Inclusion and Exclusion Criteria

Included studies were: (1) Primary reports of experimental studies with or without a comparator group, evaluating the effectiveness of an intervention, technique or practical

strategy that individuals could use to modify-impulsive processes regulating eating behavior; (2) Conducted exclusively with adults (defined as aged 18 or older); (3) Published in peer-reviewed journals in English from 1993 onwards. Articles were excluded if they: (1) involved pharmacological , physical (e.g., acupuncture) or neurophysiological therapies (e.g., cortical stimulation); (2) contained a protocol only; (3) targeted multiple or other behavioral problems, including consumption of alcohol or drug abuse; (4) focused on eating disorders; or (5) only involved case reports.

Data Sources and Search Strategy

We searched the electronic databases MEDLINE, PsycINFO, CINAHL, AMED, Web of Science in September 2014, using a comprehensive search strategy (Supplemental File:Table S1). Searches of titles, abstracts and keywords used key terms such as (impulse OR self-control OR temptation) AND (techniques OR intervention) AND (eating OR food). The terms were reviewed by several authors (SvB, JS, CG) and revised iteratively to ensure comprehensive coverage of the targeted literature. The reference lists of eligible studies were scanned for further records potentially meeting inclusion criteria.

Study Selection

The titles and abstracts of identified papers were assessed independently by two researchers in relation to our inclusion and exclusion criteria. Full-texts were obtained for relevant articles, and all were assessed by at least two authors (SvB, JS, CG). Inter-rater agreement on inclusion at both stages was assessed using prevalence and bias adjusted kappa (PABAK) statistics and any disagreements were resolved through discussion.

Data Extraction

Data were systematically extracted on study level characteristics such as design, country of origin, recruitment method, and participant characteristics. Further extraction comprised: technique(s) under evaluation, mode of technique delivery, comparison group,

follow-up period and retention, proposed underlying mechanism, and outcomes (see below), as well as the authors' interpretation of their findings.

Outcomes

Data were extracted on outcomes associated with impulsive processes (e.g., changes in attentional bias, cravings, approach/avoidance tendencies), as well as weight and behavioral outcomes such as food consumption and food choice.

Quality Assessment

Due to the wide heterogeneity of study designs, no single quality assessment tool was deemed suitable. Therefore, study quality was assessed against potential sources of bias identified by the Cochrane Handbook for Systematic Reviews of Interventions (Higgins, & Altman, & Sterne, 2011) for a wide range of study designs. These included whether there was potential for: (1) analytical bias (e.g., was the sample size adequate to detect the intended effects as evidenced by a credible a priori power calculation?); (2) sampling bias (e.g., was the sample representative of the general population or limited to particular sub-groups?); (3) selection bias (e.g., was randomization used, were groups similar at baseline, and if not was this controlled for in analyses?); or (4) measurement bias (e.g., was evidence presented for the reliability and validity of measures? Were outcome measures objective or self-reported?). A small sample is defined here as less than 60 people per group, which is the number needed to have an 80% chance of detecting a SMD of 0.5 (i.e., a medium effect size) with $p<0.05$, and a very small sample as less than 30 per group. Overall study quality was not quantified due to the different methodological issues pertaining to different study designs. Instead, the quality assessment was used to (a) highlight potential sources of bias for each study and (b) identify areas of improvement for future research.

Analysis

Due to the heterogeneous nature of the study designs, intervention techniques, outcomes, and populations involved, a quantitative meta-analysis was not undertaken. Instead, a systematic narrative synthesis (Popay et al., 2006) was used to define and categorize the identified techniques according to the targeted mechanisms of action. Outcomes data and study design characteristics were systematically collated. The evidence for effectiveness within each technique category was narratively synthesized and categorized on the basis of criteria relating to the type, quantity and quality of available studies.

Results

The searches identified 4619 articles, with six further articles obtained from reference lists and experts. After title and abstract screening, 156 full-texts were reviewed and 66 articles (identified with an asterisk in the reference list) describing 92 unique studies that evaluated at least one technique for modifying or managing eating-related impulses were included (Figure 1). The reviewers agreed on selection decisions for 98% of titles and abstracts (PABAK = 0.95), and 87% of the full-texts (PABAK =0.74).

Study and Sample Characteristics

The characteristics of the 92 included studies and 90 excluded articles are summarized in Tables S2 and S3. Most studies (85%) were conducted in the Netherlands (24), the US (21), Australia (17), and the UK (16). The studies covered a range of populations (e.g., general population, restrained eaters, overweight and obese people), however, the majority of samples comprised University staff and/or students (70) with some targeting particular groups of students such as chocolate cravers, and regular snackers. In most studies, women comprised either all (34) or the majority of the sample (42), with only six having a majority of men (See Table S2).

Study Type and Quality

Study designs included randomized controlled trials (RCTs) (43), factorial experiments (18), non-randomized controlled trials (16) and an uncontrolled (pre-post) study (1) (See Table S4-5). The majority were conducted in a laboratory or classroom (71), with the remainder being community (18) or internet-based (3). The methodological quality of the 92 studies was generally weak with a high prevalence of potentially serious biases (. The most common weaknesses were lack of randomization (28), sampling bias (70 student-only, 34 female-only), and potentially inadequate statistical power /sample size (87) See Tables S6-8 for detailed study information.

Outcomes and follow-up periods

A large variety of outcomes were measured (Table S3) including weight (4), food consumption (23), craving (23), automatic evaluations (implicit associations about the pleasantness or unpleasantness of food items) (3), delay discounting (2), and attentional bias (3). For food consumption, 19 of 23 studies objectively observed consumption through use of taste tests, ad libitum snacking, or marked sweets that were taken home and returned the following day. The majority (72) of the studies only measured outcomes post-treatment, with other follow-up periods ranging from five minutes (3) to six months (3).

Identification and categorisation of techniques and mechanisms.

The review identified 17 distinct techniques, which were categorized into three groups according to their targeted mechanisms as articulated by authors (Table S5). First, techniques that target the impulsive system directly by attempting to modify the generation or strength of impulses triggered by specific stimuli (n=6), hereafter referred to as impulse-focused techniques. Second, techniques which aim to engage the reflective system or cognitive resources in identifying and suppressing or otherwise managing urges or cravings before they are acted on (n=9), hereafter referred to as reflective techniques. Third, techniques where the mechanism was unstated or unclear (n=2) (Box S1).

Synthesis of evidence on effectiveness of techniques

Detailed evidence on the effectiveness of the 17 techniques is provided in Tables S6-8. The table for each technique category organizes the studies by technique type, then by outcome (weight, food consumption, cravings and other measures), and then by study design, with mean differences (MD) and standardized mean differences (SMD) and significance levels reported where available. This standardized structure is reflected in the sections below. Each section begins with a brief literature-based definition, followed by a discussion of the postulated mechanism of action and an evidence synthesis. Finally, each section includes a brief summary of potential sources of bias. A synthesis of the overall quality and strength of the evidence (categorised as "promising", "mixed" or "insufficient") and further research needed for each of the techniques is provided in Table S9 .

1. "Impulse-focused" techniques: targeting impulse generation or strength.

A total of 35 studies evaluated six impulse-focused techniques.

1.1 Priming **(N=9)** involves the use of cues to (re)direct behaviors. Primes automatically activate mental representations of personal concerns and goals and help to activate associated (healthy) behavioral schemas. The primes used in the 9 studies reviewed included reminders of God (2 studies), family presence (1), and love-related symbols (3).

Effects of priming on food consumption. One RCT, one non-randomized controlled trial and one factorial experiment investigated the effects of priming on food consumption. Based on a small sample (mean group size 23), the RCT (Raska & Nichols, 2012, Study 3) reported that people exposed to companionate love images (Abraham Lincoln) were significantly more likely (62% vs 29%) to choose a healthy snack post-treatment than those exposed to a sexual love image (Marilyn Monroe). One small non-randomized controlled trial (mean group size 12) also found significant reductions in observed food consumption post-treatment (SMD=1.24) for people primed with ideas about God compared with controls

(Laurin et al., 2012). The factorial experiment found no significant difference in healthy food consumption between groups post exposure to photos of loved ones (family). However, sub-group interaction effects suggested that diet primes significantly reduced post-treatment food consumption in restrained eaters (people who tend to set rigid rules about eating and normally consume more than unrestrained eaters) but not unrestrained eaters (Stillman et al., 2009). Although the three studies used objective measures of food consumption, two did not use randomization, none reported a priori power calculations, and all used student samples.

Effects of priming on hypothetical food choice. Two RCTs, one (non-randomized) crossover trial and two factorial experiments investigated the effects of priming on hypothetical food choice. The two RCTs reported positive effects of priming on hypothetical food choices after being exposed to companionate as compared to sexual love primes (SMD=0.4-0.7) or a control group (SMD=0.4) (Raska and Nichols, 2012 Studies 1 and 2). When cued to focus on the healthiness of a certain food in a non-randomized crossover trial, participants were significantly more likely to report to want to eat a food rated as healthy/untasty and significantly less likely to eat a food rated as unhealthy post-treatment, compared with controls (Hare et al., 2011). In contrast, interaction effects in two factorial experiments suggested that although priming self-control using scrambled sentence tasks improved present food choices compared with a neutral prime, it could have adverse effects on food choices for the future (self-reported post-treatment) (Laran, 2010). None of the five studies used a priori power calculations, all used students, and one did not randomize.

Effects of priming on automatic evaluations and information accessibility. One very small 3-arm RCT (N=37) showed that participants primed with the concept of God had significantly more negative automatic associations with unhealthy palatable foods than did those with either a neutral (SMD=1.03) or positive prime (SMD=1.03) (Laurin et al., 2012 Study 3). A larger factorial experiment (N=213, but with 8 groups), reported that when

primed with self-control, participants were significantly faster to recognize words related to self-control than neutral words post-treatment in the present time frame, but not in the future time frame (Laurin et al., 2012 Study 2). Both studies used student samples and did not provide a priori power calculations.

1.2 Cue-exposure **(N=9)** involves exposure to food cues to reduce future consumption. Although the use of cue-exposure may seem counterintuitive as the 'obesogenic environment' already automatically triggers eating behavior, it is posited that temptations may automatically trigger goal-directed behavior through the activation of long-term goals (Counteractive Control Theory; Trope & Fishbach, 2000).

Effects of cue-exposure on food consumption. One RCT, one (non-randomized) crossover trial, and three factorial experiments examined effects of unhealthy food cues (e.g., smell of cookies baking) on subsequent observed food consumption. The RCT found that exposure to strong temptations led to significantly higher self-reported calorie estimates post-treatment, compared to weak temptations (Kroese et al. 2013). The crossover trial compared diet congruent and temptation cues and found no significant difference between groups post-treatment. One factorial experiment reported a significant difference in observed snack consumption between Non-Actionable Food Temptation cues, Actionable Food Temptation cues, and controls (Geyskens et al., 2008). Subgroup analyses showed conflicting findings: Coelho et al.'s (2009) results suggest that post-treatment food consumption was significantly reduced in restrained but not unrestrained eaters exposed to food (temptation) cues, compared with controls. Buckland et al. (2013) found the opposite (i.e. restrained dieters consumed fewer total calories following a pro-diet cue, compared to a temptation cue). Geyskens et al. (2008) found that Non-Actionable Food Temptation cues were associated with increased consumption post-treatment compared to controls for low convenience, but not high convenience, foods. This study also reported that for high, but not low convenience foods,

Actionable Food Temptation cues were associated with increased food consumption compared to controls. All but one study involved small sample sizes, all used students, none provided a priori power calculations, only one used randomization.

Effects of cue-exposure on craving. One non-randomized controlled trial reported that repeated cue-exposure without an eating response, significantly reduced craving scores at up to 3 days follow-up, compared to controls (van Gucht et al., 2008). A small student sample was used, no a priori power calculation was provided, and there was no randomization.

Effects of cue-exposure on goal activation. A non-randomized controlled trial and a factorial experiment examined the effects of unhealthy food-cues on goal activation (Geyskens et al., 2008 Studies 1 and 2). Both actionable (bowl of chocolates) and non-actionable food cues (pictures) significantly increased the activation of goals to restrict food consumption post-treatment compared to controls (SMD=0.56 and 0.90 respectively). These studies had small student samples. no a priori power calculations or randomization.

Effects of cue-exposure on goal importance and intentions. Two non-randomized trials (Kroese et al., 2009) found that post exposure to temptation cues, both dieting goal-importance and goal intentions were self-reported to be significantly more important compared with controls. Both studies used small student samples. without a priori power calculations and lacked randomization.

Effects of cue-exposure on attention processing. One 3-arm RCT (Geyskens et al., 2010) found a significant difference in attention processing (attention being drawn away from food) favouring actionable food temptation and non-actionable temptation compared with a control group post-treatment. This RCT used a small student sample without a priori power calculations.

1.3 Inhibition training **(N=9)** involves repeatedly practicing an inhibitory response to presentations of images that are paired with stop cues. Inhibitory control represents higher-

order processes that can inhibit pre-potent (pre-conscious) actions, and facilitate deliberate executive control. Inhibition training aims to improve inhibitory control, by the automated response inhibition following repeated cue association training.

For example Veling and colleagues (2011) examined whether stop signals presented in a "go /no-go" task, can be used to control chronic dieters' subsequent consumption of palatable foods. In such tasks, images of high palatable foods are consistently paired on a screen with stop-signals (No-go) in an attempt to train inhibition of the existing automated behavioral response. The participant is asked to either perform or withhold a certain action (e.g., pressing the spacebar), depending on the accompanying signal. We found nine studies that evaluated the effects of inhibition training.

Effects of inhibition training on food consumption. Two RCTs and two factorial experiments, found that Inhibition Training significantly reduced subsequent observed food consumption post-treatment compared to impulsivity promotion training (Guerrieri et al., 2012) and control groups (Houben & Jansen, 2011; van Koningsbruggen et al., 2014). However, two RCTs and one non-randomized crossover trial found no significant effects of training on food consumption, compared with controls, post-treatment (Guerrieri et al., 2012; Houben, 2011) or at one-day follow-up (Veling et al., 2011). Sub-group effects within one RCT and one non-randomized crossover trial suggested that inhibition training may have positive effects on food consumption at one-day of follow-up only for people with relatively low inhibitory control (Houben, 2011), and may be particularly beneficial for chronic dieters and those with high appetite (Veling et al., 2011). Only two of the 6 studies provided a priori power calculations (van Koningsbruggen et al., 2014), and all six used small student samples.

Effects of inhibition training on hypothetical food choice. Two RCTs (Veling et al., 2013 Study 1&2) found that Inhibition Training significantly reduced unhealthy hypothetical food choices post-treatment compared to control groups. However, in sub-group analyses

these positive effects were only apparent for people with high appetite and relatively high frequency of past behaviors towards the trained foods . These studies used small sample sizes, but were not conducted with students.

Effects of inhibition training on response time tasks. One non-randomized crossover trial found reduced impulsive responding toward food stimuli immediately post-treatment (Veling et al., 2011). However, this study used a small student sample and did not randomise.

***1.4 Physical activity* (N=6)**. Undertaking active tasks such as exercise or walking. It has been proposed that physical activity stimulates pleasure-reward centres in the brain, interfering with the association between a range of unhealthy behaviors and stimulation of (the same) pleasure-reward centres (e.g. van Rensburg, Taylos, Hodgsons et al., 2009).

Effects of physical activity on food consumption. One factorial experiment reported significant reductions in ad libitum snacking post-treatment, with 13.2g less chocolate consumed after exercise compared to controls (Oh & Taylor, 2012). One randomized crossover trial reported a significantly longer time (of almost 50%) before next snack consumption following exercise compared to a control task (Thayer et al., 1993). Neither study used a priori power calculations and both had small sample sizes.

Effects of physical activity on craving. Four randomized crossover trials of physical activity reported reductions in cravings and desire to eat at up to 10-minutes of follow-up compared to a control task (d= 0.6-0.8) (Taylor & Oliver, 2009; Thayer, 1993; Oh & Taylor, 2013; 2014). However, in one study the maintenance of effects up to 10 minutes was only seen after vigorous, but not moderate, exercise (Oh & Taylor, 2014). Although sample sizes were small in these four studies, two did provide a priori power calculations to determine the number of participants needed for their study.

Effects of physical activity on attentional bias. Two of the above randomized crossover trials reported that a 15 minute brisk walk or cycling significantly reduced

attentional bias, compared with passive controls post-treatment (d=0.42 to 1.42) (Oh & Taylor., 2013; 2014).

1.5 Attentional bias training **(N=2)** modifies impulses by changing existing attentional biases towards environmental stimuli such as highly palatable, energy dense foods. Attentional bias is the selective attention to relevant information, in this case food cues, over neutral information. It is posited that cues that are associated with a reward (through conditioning) automatically capture attention and raise the salience of behavior-reward schemas (Incentive Sensitization Theory; Robinson and Berridge, 1993). Attentional bias training involves retraining attention away from food cues using a computer-based modified dot probe procedure which directs attention away from the conditioned unhealthy stimulus by following a target that is presented near non-food pictures (Kemps et al., 2014).

Effects of attentional bias training on food consumption. Two studies using attentional bias training reported conflicting results. In one RCT attentional bias was significantly reduced from baseline to post-treatment after 'avoid' compared to 'attend' training (i.e. avoiding vs. attending to chocolate cues) with medium effect sizes. This translated into significant differences in observed consumption of chocolate muffins (d=0.67) but not blueberry muffins between the groups post-treatment (Kemps et al., 2014). In contrast, a smaller non-randomized controlled trial reported no significant differences in attentional bias or food consumption post-treatment between 'attend' training (i.e. towards cake), avoid training (i.e. away from cake), and controls (Hardman et al., 2013). These two studies both used small student samples and did not report a priori power calculations..

Effects of attentional bias training on craving. Although the RCT (Kemps et al., 2014) reported successful attentional bias modification, this did not translate into significant differences in cravings between the 'avoid' and 'attend' training groups post-treatment.

1.6 Approach/avoidance training **(N=1).** Following the automatic capturing of attention (as above), reward stimuli trigger a motivational response that directs behavior toward target acquisition and consumption (an 'approach' tendency). Approach/Avoidance training aims to modify the association to approach, thereby reducing craving and consumption. Like attentional bias training, this technique draws on Incentive-Sensitization Theory (Robinson & Berridge, 1993) and cognitive-motivational models of craving (e.g., Franken, 2003; Kavanagh, Andrade & May, 2005).

Effects of approach/avoidance training on approach bias and craving. In the only study on this technique, Kemps et al. (2013) conducted a two-arm RCT with 96 female students. They found that both approach bias and cravings associated with chocolate were significantly reduced post-treatment (d=0.5) for people receiving 'avoid' compared to 'approach' training. However, this study was conducted with a student sample, no a priori power calculation was used, and the sample sizes were small (48 per group).

2. "Reflective" techniques: engaging the reflective system or cognitive resources.

A total of 55 studies investigated 9 distinct reflective techniques.

2.1 Mindfulness-based strategies **(N=19)** aim to raise awareness of the present moment by purposefully paying attention, without judgment, to the current experience that is unfolding, and observing its path without acting. Repeated exposure to eating cues without taking action is expected to result in reduction of the eating response, due to a disassociation between cue and reward. These strategies require the individual to bring the experience and decision making process into conscious awareness. Mindfulness-based strategies include acceptance-based strategies in which the goal is to experience and observe eating urges or cravings whilst not taking action (e.g. Forman et al., 2013a). Distraction-oriented mindfulness strategies are also possible, whereby participants are taught to fully experience any thoughts

and feelings while focusing on other things, such as their breathing (Breath Focus) or parts of the body (Body Scan) (e.g. May et al., 2010).Nineteen studies, including 10 (53%) RCTs, four (21%) factorial experiments, four (21%) non-randomized trials, and one (5%) uncontrolled study examined mindfulness-based strategies (described as acceptance, defusion, mindful eating, body scan, and breath focus).

Effects of mindfulness-based strategies on weight. Three RCTs found no significant differences in weight loss post-treatment (after intervention periods ranging from 8-40 weeks) or at up to 6-month follow-up, compared to "standard behavioral treatment" involving control-oriented coping strategies such as cognitive restructuring or problem solving (Alberts et al., 2010; 2012; Forman et al., 2013a). However, these RCTs found significant reductions in weight within both treatment groups. A subgroup analysis in one large RCT (N=128) showed that weight loss was significantly greater (6.1% more (SMD=0.74) at 6-months in the mindfulness group when the treatment was delivered by experts, compared to those receiving standard behavioral treatment (Forman et al., 2013a). A further uncontrolled study found a significant change in weight of 9.6% at 6-month follow-up (SMD= 0.58) (Forman et al., 2009). Two of the RCTs had small samples and none reported a priori power calculations. The uncontrolled study examining weight had high drop-out (50%), leaving only 14 participants available for analysis.

Effects of mindfulness-based strategies on food consumption. One RCT and two non-randomized controlled trials reported significant decreases in self-reported or observed calorie consumption post-treatment (SMD= 0.45-0.99), compared with controls (Jordan et al., 2014; Hooper et al., 2012) and generic relaxation training (Jenkins & Tapper, 2014). Intervention participants in one further RCT were significantly more likely to self-report abstinence from chocolate at seven-day follow-up compared with controls (Odds ratio 4.61) and with cognitive restructuring groups (Odds ratio 3.26) (Moffitt et al., 2012). Two further

RCTs reported no significant difference in observed chocolate consumption post-treatment between mindfulness and cognitive control-based coping(Forman et al., 2007; 2013b). None of these six studies reported a priori power calculations, three of the six used small samples, and only two did not use students (Forman et al., 2013b; Moffitt et al., 2012).

Effects of mindfulness-based strategies on food craving. The evidence here was also mixed. Three RCTs and three non-randomized trials found no significant post-treatment differences in craving between mindfulness and cognitive control-based coping groups (Forman et al., 2007; 2013b; Hooper et al., 2012; May et al., 2010 Study 1; Moffitt et al., 2012). Compared with non-active control groups, two RCTs (Moffitt et al., 2012; Forman et al., 2007) and two non-randomized trials (Hooper et al., 2012; May et al., 2010 Study 2) found no significant post-treatment differences in craving and two RCTs (Alberts et al., 2013; May et al., 2010 study 1) found significantly *increased* post-treatment craving scores in the mindfulness group compared with controls and at 20-minute follow-up. In contrast, three further RCTs found significant reductions in cravings compared with controls post-treatment (Alberts et al., 2010; 2012; Hamilton et al., 2013). Sub-group analyses in one RCT reported significantly reduced craving scores post-treatment compared with controls only for participants who were highly susceptible to food cues (Forman et al., 2007). None of the 10 studies reported a priori power calculations, nine used small samples, 6 of the 10 used students, and three were not randomized.

Effects of mindfulness-based strategies on discounting and approach bias. One RCT found a significant reduction in impulsive delay, and risk-averse probability discounting patterns (change in preferences for different sized rewards depending on the delay) for those who were trained to eat mindfully compared with controls post-treatment (Hendrickson & Rasmussen, 2013). In addition, four factorial experiments reported significant effects on approach biases post-treatment and at up to 5-minutes follow-up (Papies et al., 2012, Studies

1, 2a, 2b and 3). The five studies had small or very small samples, none reported a priori power calculations, one did not use randomization, and all but one used students.

2.2 Visuospatial Loading **(N=16)** refers to the use of tasks that occupy the sensory modalities associated with craving (i.e., sight or smell) to reduce the resources available for cognitive elaboration. It is proposed that craving episodes are triggered by both external and internal cues. External cues trigger automatic, associative processes resulting in spontaneous intrusive thoughts about the object of desire. These thoughts are then elaborated with visual and olfactory imagery of consumption, as well as eating-related cognitions. Mental imagery is held to be an important process affecting the maintenance and intensity of a craving (Elaborated Intrusion theory; Kavanagh et al., 2005). Thus, tasks that occupy the sensory modalities and so reduce the available cognitive resources have been hypothesized to reduce craving intensity by preventing development of mental imagery that would otherwise elaborate the craving. Sixteen studies examined visuospatial loading using delivery methods such as clay modelling, dynamic visual noise, visual imagery, and olfactory interference.

Effects of visuospatial loading on food consumption. One small RCT (group size 24, with no a priori power calculation) found that dynamic visual noise delivered on a hand held device significantly reduced self-reported craving-related consumption (SMD=0.49) in female students post-treatment, compared with controls (Kemps & Tiggemann, 2013a).

Effects of visuospatial loading and olfactory interference on craving. Six RCTs (Andrade et al. 2012; Kemps & Tiggemann, 2007 Studies 1 and 2; 2013a; Knauper et al., 2005; Rodriguez-Martin et al., 2013), one factorial experiment (Harvey et al., 2005), eight (non-randomized) crossover studies (Kemps & Tiggemann, 2013b; Kemps et al., 2004; 2005; 2008; 2012; Steel et al., 2006), and one non-randomized controlled trial (Andrade et al., 2012) showed that visuospatial loading and olfactory interference tasks significantly reduced cravings post-treatment and at up to 3-months follow-up, compared with controls and

comparison groups using tasks that did not engage craving-related sensory modalities. None of these 16 studies provided a priori power calculations, 13 used small samples, all used self-report measures, and the majority used student samples.

2.3 **Implementation Intentions** (if-then plans) **(N=9).** Forming an implementation intention involves identification of a cue that will be encountered in daily activities and consciously resolving to take a particular action when it is encountered. This technique can be used to manage impulsive processes. Although such plans initially require conscious deliberative planning, when the targeted temptation situation is encountered, the planned response may be initiated swiftly, automatically, and without need for conscious intent (Gollwitzer & Sheeran, 2006). Alternatively, the planned response may act as a trigger to bring decision making into conscious awareness, engaging the reflective system to override any undesirable impulses. The if-then planning components used in the six studies below involved either pre-specified responses such as 'then I will think of dieting', 'then I will ignore that thought' or self-formulated plans (e.g., Hofmann et al., 2010).

Effects of if-then planning on food consumption. One RCT reported that people forming impulse related implementation intentions had significantly reduced self-reported food consumption (SMD=0.41) compared with controls up to one-week follow-up (Achtiziger et al., 2008). Two factorial experiments (van Koningsbruggen et al., 2014 Studies 1 and 2) tested implementation intentions with or without inhibition training. These studies found a significant reduction in observed food consumption for both techniques compared with controls. However, these effects only occurred in the absence of the other technique (i.e., the intervention strategies both worked, but they did not have additive effects). One further RCT found no main effect for either implementation intentions or the "go /no-go" treatment although analysis of sub-group effects suggested that implementation intentions may have positive effects on food consumption at up to two-weeks follow-up only for

unsuccessful dieters, as opposed to successful dieters or normal eaters (van Koningsbruggen et al., 2011). Only two of the above four studies reported a priori power calculations,all but two studies, used student samples, and two were based on self-report.

Effects of if-then planning on goal activation and automatic evaluations. One RCT reported significantly less positive automatic evaluations of, and explicit attitudes towards, food post-treatment for implementation intentions compared with controls (Hofmann et al., 2010). Sub-group analyses in a further RCT suggested that 'think-of-dieting' if-then plans may activate the diet goal for unsuccessful dieters but not successful dieters or normal eaters post-treatment, compared with controls (van Koningsbruggen et al., 2011). Neither study reported a priori power calculations but one used a relatively large sample (140 students).

Effects of other planning on food choice /consumption. Three studies evaluated planning (but not necessarily involving if-then plans) of daily food consumption, including defining sequences of action steps and personal behavioral guidelines. The setting of behavioral guidelines is hypothesized to prime and remind the individual of their higher order goals in temptation situations.

Townsend & Liu (2012) conducted two RCTs and a factorial experiment in which there were no significant effects of planning on healthy versus unhealthy food choices compared with controls. However, subgroup analyses in one RCT suggested that planning might only benefit those who consider themselves of average weight. For those who rated themselves as overweight, or very overweight planning was associated with a significantly increased likelihood of choosing an unhealthy snack post-treatment. Subgroup analyses in a second RCT suggested that concrete (as opposed to abstract) planning significantly increased the likelihood of those with a higher body fat percentage choosing an unhealthy snack option post-treatment, compared with controls. One factorial experiment found no effects of planning or weight perception on snack choice, nor any significant interaction effects post-

treatment (Townsend & Liu, 2012). All three studies used student samples and they did not provide a priori power calculation. However, they did have larger than average sample sizes (50 or more per group). The subgroup analyses break randomization and so these findings should be considered as associations, rather than causal evidence.

2.4 Cognitive Loading **(N=3)** involves use of tasks that occupy working memory using resources which are required for recognizing the hedonic value of foods. This in turn prevents the triggering of craving-related cognitive elaborations (i.e., craving imagery) (van Dillen et al., 2013). Three studies investigated cognitive loading, in the form of remembering a number with a large digit span.

Effects of cognitive loading on craving and other outcomes. One non-randomized controlled trial reported that compared to low cognitive loading tasks, high cognitive loading reduced craving post-treatment (SMD= 0.41, p=0.052) and significantly reduced attentional bias toward attractive food stimuli post-treatment (van Dillen et al., 2013 Study 1). High cognitive loading also significantly reduced hedonic responses to food stimuli compared with moderate loading and controls post-treatment (van Dillen et al., 2013 Study 2). Sub-group analysis in one non-randomized controlled trial suggests that cognitive loading significantly reduced the likelihood of choosing an unhealthy snack post-treatment compared with controls, but only for those who were highly susceptible to food cues (van Dillen et al., 2013 Study 3). None of these three studies reported a priori power calculations with small samples (group sizes ranging from 23 to 47), and all used paid volunteers in a University setting.

2.5 Thought Suppression **(N=3)** involves actively avoiding thinking about something with the intention to prevent engaging in associated undesirable behaviors. Thought suppression is often used as a strategy in the struggle against unwanted thoughts (Wenzlaff & Wegner, 2000) as a means of direct behavioral control (Baumeister, Heatherton, & Tice,

1994). However, suppressionhas also been hypothesized to lead to hyperaccessibility of the thoughts (Wegner, 1994) as well as behavioral rebound (Erskine et al., 2008).

Effects of thought suppression on food consumption and cravings. One RCT and two non-randomized controlled trials investigated the effects of thought suppression. Johnston et al. (1999) found a significant increase in effortful behavior to gain chocolates post-treatment for a group instructed to suppress thoughts of chocolate compared with controls (SMD=0.67). Two non-randomized controlled trials (Erskine et al., 2008; 2010) reported a similar effect, with thought suppression significantly increasing chocolate consumption post-treatment, compared with controls and participants who were instructed to 'express' any thoughts about their intentions to eat chocolate. However, subgroup analyses suggested that this behavioral rebound effect was only present for 'restrained eaters'. None of the three studies provided a priori power calculations, and all used small samples.

An additional RCT and two non-randomized controlled trials included thought suppression as a comparison group, but focused on assessing mindfulness-based strategies. One non-randomized trial reported that the thought suppression group ate significantly more post-treatment, compared with controls (SMD=0.38) and with a mindfulness treatment group (Hooper et al., 2012). The RCT reported that thought suppression significantly increased craving post-treatment and at up to 20-minutes follow-up (SMD=0.9 and 0.74, respectively) compared with controls (Alberts et al., 2013). In contrast, the other non-randomized controlled trial reported that craving levels remained constant up to post-treatment in a thought suppression group, whilst they increased in a mindfulness group (May et al., 2010).

2.6 Cognitive restructuring **(N=5)** is a form of cognitive stimulus control which involves altering the meaning of a situation or object so that the response to it is changed. This consists of considering a food item and either imagining it in a context that is not associated with consumption (e.g., marshmallows are pink fluffy clouds), or imagining

negative aspects of the item (e.g., someone sneezed on it). With repetition, this may change positive automatic evaluations towards unhealthy food (Hoffman et al., 2010).

Effects of cognitive restructuring on weight. Two studies with weight outcomes used cognitive restructuring in their study comparisons (Alberts et al., 2010; Forman et al., 2013a), as control groups in studies assessing the effects of mindfulness and are reported in the above sections. These studies found significant reductions in weight for both groups, but no differences between the groups (See above text and Table S7).

Effects of cognitive restructuring on craving. In one non-randomized crossover trial cognitive restructuring significantly reduced self-reported desire to consume both craved foods and other foods post-treatment, compared with instructions to look at food and imagine consumption (SMD=1.81) (Guiliani et al., 2013). However, this study provided no a prior power calculations (group size = 82).

Effects of cognitive restructuring on automatic evaluations. Two RCTs compared cognitive restructuring with a control group or implementation intentions and found that both implementation intentions and restructuring (SMD=0.52) resulted in significantly less positive automatic evaluations of chocolate post-treatment, compared with controls (Hofmann et al., 2010 Study 1 and 2). In one of these RCTs cognitive restructuring generated significantly more positive automatic evaluations than implementation intentions post-treatment (Hoffmann et al., 2010, Study 1). Neither of the studies provided a priori power calculations but one RCT had group sizes of over 100.

2.7 Emotional freedom technique (EFT) **(N=1)** is a meridian-based intervention employing stimulation of acupressure points through a tapping motion whilst keeping the mind focused on the negative emotion. This technique is postulated to restore the energy balance of the body and eliminating the negative experience (such as cravings) which had initially caused the disturbances in the energy field (Craig, 2011). It is similar to some

mindfulness-based techniques where "in the moment" attention is paid to one's thoughts and feelings, in the absence of action, thereby deconditioning the previously automated response to an unhealthy eating cue. However, it is claimed that EFT actively counteracts the negativity by restoring the body's energy balance.

Effects of emotional freedom technique on weight, craving, and susceptibility to food. One RCT (Stapleton et al., 2011) investigating the effects of four two-hour sessions of EFT involving eight acupressure points found no differences in weight loss between the EFT and control groups post-treatment or after six months. However, EFT significantly reduced cravings (SMD=0.90) and self-reported susceptibility to food post-treatment (SMD=0.68). No a priori power calculations were provided and there was a 52% loss to follow-up.

2.8 "I don't" refusal framing **(N=1)** uses self-talk to increase the salience of temptation resistance schemas. It has been theorized that using self-talk phrased along the lines of "I don't eat X" versus "I can't eat X" each time you are exposed to the relevant temptation, invokes a degree of empowerment and control, resulting in a differential influence on the success of subsequent self-regulation processes (Self-Determination Theory; Deci & Ryan, 2000; Patrick & Hagtvedt, 2012).

Effects of "I don't" refusal framing on food consumption. One non-randomized controlled trial (Patrick & Hagtvedt, 2012) found that students using "I don't" refusal framing were significantly more likely to choose a healthy snack post-treatment compared to those instructed to use "I can't" refusal framing. However, subgroup analyses suggested this only benefitted those who felt healthy eating was a highly relevant goal. The study used a student sample, did not use randomization, and provided no a priori power calculation.

2.9 Autonomous learning conditions **(N=1)** involve facilitating the setting of goals reflecting one's own values (rather than external rewards, approval, or punishments). It is posited that autonomous learning is less depleting to the cognitive resources required for

inhibition and control (Moller, Deci, & Ryan, 2006). Self-determination theory suggests that individuals who set goals in autonomous learning conditions should snack less than those who set goals in conditions with external controls such as close supervision and who use external (as opposed to internal) rewards or punishments to reinforce the target behavior.

Effects of autonomous learning conditions on food consumption. One RCT showed that students in the autonomous learning condition consumed significantly fewer jelly beans post-treatment (SMD=0.7) compared with the controlled learning comparison group (Magaraggia et al., 2013).

Effects on subsequent self-control. In the same RCT, the autonomous learning group showed significantly better performance on a self-control task post-treatment compared with controls. This study did not provide an a priori power calculation and used a student sample.

Discussion

This review has for the first time systematically identified and categorized techniques used to modify and manage impulsive processes. For each technique we have also synthesized evidence of its effectiveness for regulating eating. Six impulse-focused and nine reflective techniques were identified, as well as two techniques with unclear mechanisms of action. Most of the research to date (44 studies on nine techniques) has been directed towards managing impulses once they become available to conscious awareness (e.g., using mindfulness techniques). Less research (35 studies on six techniques) has targeted processes that affect the initial generation or strength of eating impulses (priming, cue exposure, physical activity and interventions to modify attentional bias, approach /avoidance tendencies, and inhibitory control) in most cases through the use of associative training tasks. The review highlights a series of impulsive mechanisms and related change techniques that can usefully supplement available taxonomies of change techniques (e.g., Abraham, Southby,

Quandte, Krahé, & van der Sluijs, 2007; Abraham & Michie, 2008; Michie et al., 2013; Michie et al., 2011; Schulz, Czaja, McKay, Ory, & Belle, 2010). However, the quality of the evidence available limits the conclusions we can draw. Potentially important sources of bias were identified in the majority of studies. Most studies involved small numbers of participants and did not report a priori power calculations and therefore probably underpowered to detect the hypothesized effects.

Despite these areas of potential bias, there are patterns in the data which suggest that some techniques can help to reduce cravings and food consumption in the short term. Visuospatial loading, physical activity, and if-then planning showed promising evidence for effectiveness in reducing cravings and food consumption for up to one-week follow-up. Mindfulness-based strategies showed mixed evidence in relation to weight loss and food intake, and inhibition training showed mixed evidence in relation to food intake. However, this may be due to the use of active control groups to which mindfulness-based strategies were compared, and within group comparisons did suggest such strategies might produce weight loss at up to 6-months follow-up. In addition, for inhibition training the studies showing evidence for effectiveness are of better quality then those showing no evidence. Therefore, these techniques might still be considered promising in relation to weight loss and food intake, respectively. Although we found insufficient evidence on approach bias modification, it is worth noting that it has shown potential in the field of alcohol consumption (e.g., Wiers et al., 2010; 2011). Conversely, evidence from smoking cessation (Erskine et al., 2010) and from studies of smoking and alcohol use (Palfai et al., 1997), suggests that thought suppression is not an effective technique.

Most of the techniques identified are still in the early stages of development, having been evaluated in primarily lab-based studies with predominantly female student samples. To extend the evidence base, it is important to test the effects of these techniques among

members of the general public or clinical samples wanting to lose weight. In addition, most of the evidence pertains to effects lasting only a few minutes post-treatment, and further research is needed on the longer-term effects of these techniques. Therefore, as outlined in Table S9, before recommending any of the techniques for use in public health interventions, it is important to investigate their effectiveness (1) in the longer-term, (2) in general or clinical populations wanting to lose weight, (3) using "real-world" contexts, and (4) in sufficiently powered randomized studies. There may also be scope for more research on techniques that have not yet been applied to eating behavior, drawing on the wider literature on techniques for compulsive disorders, managing alcohol, or other addictive behaviors.

Strengths and Limitations

Rigorous systematic reviewing methods were used at each stage of the review, including a comprehensive search strategy, screening by multiple researchers (with high levels of agreement), structured data extraction, quality appraisal, and a systematic approach to narrative synthesis of the evidence. Nonetheless, several limitations need to be acknowledged. First, like other systematic reviews, the evidence presented in this review is potentially subject to publication bias. Second, the inconsistent use of terminology within the research literature may have limited the ability of the search strategy to identify all relevant studies. Third, our inclusion criteria excluded several studies with younger participants (e.g., Veling et al., 2014; van Gucht et al., 2010). Although meta-analyses were not conducted, this might be possible for some of the techniques which have evidence from multiple trials, such as mindfulness, inhibition training, and visuospatial loading. Indeed, since conducting this systematic review a meta-analysis has suggested that inhibition training can positively influence health behavior (alcohol consumption and eating behavior) in the short-term (Allom, Mullan, & Hagger, 2015). It is worth noting that we combined general inhibition training (i.e., Guerrrieri et al., 2012) and food specific inhibition training (e.g.,Veling et

al.,2011). However, a more recent study found significantly greater reductions in self-reported snack intake and weight loss for the food specific training, compared with general inhibition training (Lawrence et al., 2015). In addition, some overlap with our categorizations needs to be acknowledged. For example, physical activity has been classed with impulse-focused techniques, as the mechanism proposed by the authors involves non-conscious suppression of eating impulses as a result of physical activity stimulating reward centres in the brain. However, it could be argued that to engage in physical activity requires reflective control, and that the activity could potentially function as a distraction technique after conscious awareness of an impulse. Conversely, cognitive restructuring and if-then planning were both classified as reflective techniques but should eventually elicit automatic responses to suppress the future generation of impulses.

Conclusions

A range of techniques have been developed and tested for modifying and otherwise managing eating impulses. Although higher quality evidence is needed to draw definitive conclusions, visuospatial loading, physical activity, and if-then planning show promise for modifying cravings, and unhealthy food consumption. Mindfulness-based strategies and inhibition training also require further evaluation to clarify the currently mixed evidence base. High-quality, adequately-powered RCTs are now needed to establish the longer-term effectiveness and cost-effectiveness of impulse management interventions to modify eating behavior and weight in real world, community-based studies.

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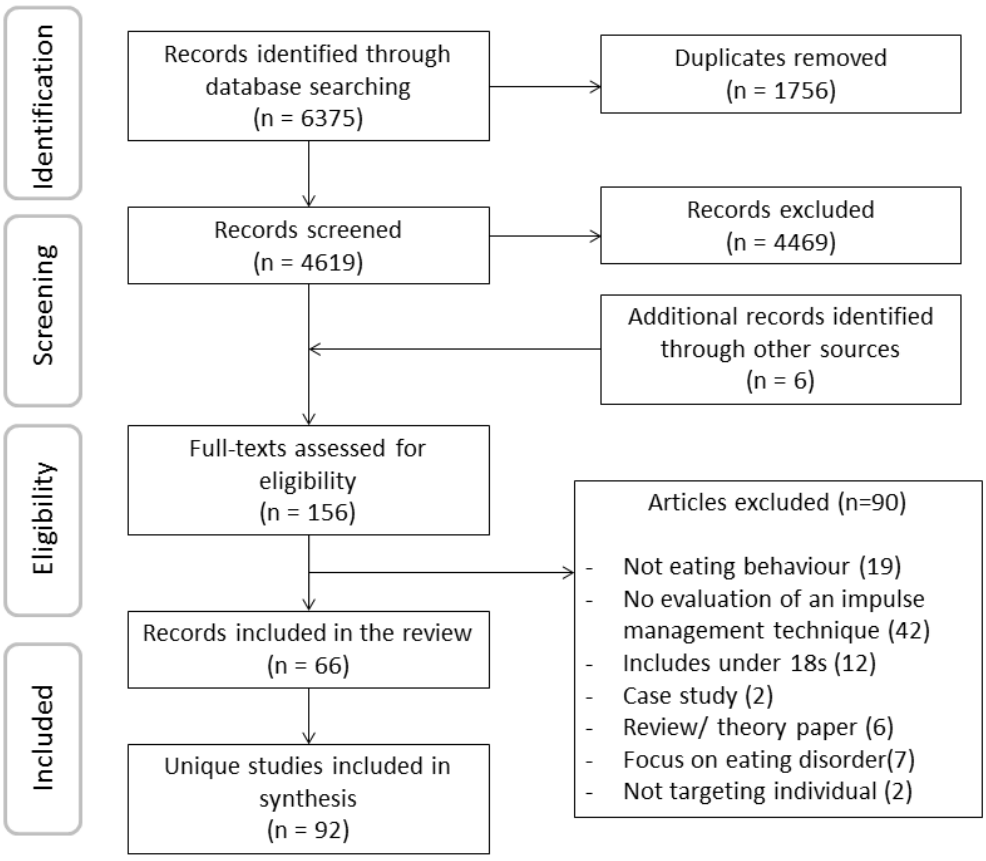

Figure 1 Study selection flowchart