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Cognitive training as a potential treatment for overweight and obesity: A critical review of the evidence

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ABSTRACT

The aim of this review is to critically evaluate the effectiveness and candidate mechanisms of action of psychological interventions which aim to either (a) improve the capacity for self-regulatory, reflective processes or (b) reduce the impact of automatic appetitive processes, in an attempt to influence food intake and associated weight-gain. Our aim was to examine three important issues regarding each type of intervention: i) whether the intervention influenced behaviour in the laboratory, ii) whether the intervention influenced behaviour and/or body mass index in the real world, and iii) whether the proposed mechanism of action was supported by evidence. We systematically searched three commonly used databases and identified 32 articles which were relevant to at least one of these issues. The majority of studies attempted to manipulate food intake in the laboratory using associative learning paradigms, in normal-weight female participants. Most of the laboratory studies demonstrated the predicted effects of interventions on behaviour in the laboratory, but studies that attempted to translate these interventions outside of the laboratory yielded more mixed findings. The hypothesised mechanisms of action received inconsistent support across studies. We identified several limitations which may complicate interpretation of findings in this area, including heterogeneity of study methods, small sample sizes, and absence of adequate control groups. We provide recommendations for future studies that aim to develop and evaluate these promising interventions for the reduction of overweight and obesity.

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1. Introduction

Rates of overweight and obesity continue to increase globally, and are now considered as the number one health concern in the developed world. Obesity has doubled worldwide since 1980 and current estimates suggest that approximately 1.9 billion adults are overweight and 600 million are obese (WHO, 2016). This upward trend is partially attributable to the rise of the 'obesogenic' environment, which has occurred rapidly over the previous 30 years. The obesogenic environment is 'the sum of influences that the surroundings, opportunities, or conditions of life have on promoting obesity' (Swinburn, Egger, & Raza, 1999) and includes but is not limited to an increase in food advertisements, and availability of cheap, unhealthy and energy dense foods, which act as triggers for unhealthy and unrestricted food consumption (Boutelle, Fulkerson, Neumark-Sztainer, Story, & French, 2007; Boyland et al., 2016).

Despite our obesogenic environment there is substantial variability in overweight and obesity within the population, therefore individual differences must play a considerable role in determining eating behaviours and associated weight gain. Distinct cognitive and behavioural processes/characteristics may confer vulnerability to overweight and obesity, but fortunately these processes/characteristics may be modifiable (Jansen, Houben, & Roefs, 2015). Dual-process models of overweight and obesity suggest that eating behaviour is guided by two distinct processes, termed automatic and reflective processes (Hofmann, Friese, & Strack, 2011; Strack & Deutsch, 2004). Whilst we discuss these processes separately below it is worth noting that some theorists suggest that these processes are not distinct from each other; rather, a continuum of processing styles or a single overriding system controls all behaviour (see discussion in Evans & Stanovich, 2013). Nevertheless, these models attempt to explain the conflict between long-term health goals and (unhealthy) eating behaviours, for example why we reach for a delicious piece of chocolate cake despite our intentions to lose weight.

Automatic processes (also referred to as impulsive or implicit processes) are the outcome of associative pairings between food-related cues (e.g. the sight and smell of food) and the rewarding effects of consumption of those foods. Once established, these processes are thought to influence eating behaviour relatively automatically (i.e., 'bottom-up'). For example, food-related cues might automatically capture the attention, evoke approach responses, and be evaluated positively (Strack & Deutsch, 2004; Wiers, Ames, Hofmann, Krank, & Stacy, 2010). These reactions might occur without placing demands on cognitive resources and they may over-ride conscious intentions to behave in a different way (i.e. to resist the piece of chocolate cake and stick to a planned diet). In other words, automatic processes may prompt people to 'eat without thinking'.

We would be slaves to the food-related cues in our environment if it were not for reflective processes (also referred to as controlled or explicit processes; Verbruggen, McLaren, & Chambers, 2014). Reflective processes are 'top-down', usually experienced consciously, and they are closely linked to higher-order 'Executive

Functions' (EFs). EFs play a key role in human behavioural expression and are associated with intelligence (Arffa, 2007), academic achievement (Best, Miller, & Naglieri, 2011) and general goal-directed behaviours (Hofmann, Schmeichel, & Baddeley, 2012; Mischel et al., 2011). Theoretical models and experimental investigations have identified distinct but related EFs (Miyake & Friedman, 2012; Miyake et al., 2000), referring to abilities which i) monitor, add to and remove information from *working memory* (updating), ii) *inhibit* dominant or well-established responses (inhibition), iii) *shift* between tasks or mental sets (shifting).

A key prediction of dual-process models is that social and health-related behaviours can be framed as a conflict or imbalance between these two systems (Hofmann, Friese, & Strack, 2011; Strack & Deutsch, 2004). For example, a weak self-regulatory (reflective) system would be easily overwhelmed by strong impulsive, appetitive responses to food-related cues and therefore behaviour would be driven towards unhealthy foods in the environment. Alternatively, these automatic appetitive responses to food-related cues might be kept in check by a strong-self regulatory system. In support of this claim Hofmann, Friese, and Roefs (2009) demonstrated that reflective processes (executive attention, inhibitory control and affect regulation) moderated the effect of automatic affective reactions to candy on subsequent candy consumption across three studies, such that automatic affective reactions had a stronger impact on consumption for individuals with poorer reflective abilities. Also, Lawrence, Hinton, Parkinson, and Lawrence (2012) demonstrated that increased activation in the nucleus accumbens (indicative of reward sensitivity) predicted BMI, but only in individuals with low self-control. Longitudinal evidence provided by Nederkoorn, Houben, Hofmann, Roefs, and Jansen (2010) demonstrated neither inhibitory control or implicit preference for snack foods predicted weight gain over one year in isolation but an interaction between the two did, such that individuals with high implicit preference and low inhibitory control gained the most weight.

Importantly, theoretical models predict both the reflective and impulsive systems are amenable to change (Friese, Hofmann, & Wiers, 2011; Wiers, Gladwin, Hofmann, Salemink, & Ridderinkhof, 2013), and laboratory findings have supported these predictions. For example, repeated practice but also training on EF tasks may prompt increases in EF capacity in the laboratory (Manuel, Bernasconi, & Spierer, 2013) and in the real-world (Berkman, Kahn, & Merchant, 2014; Klingberg, 2010; Thorell, Lindqvist, Nutley, Bohlin, & Klingberg, 2009), however this may not always occur (Cohen & Poldrack, 2008). Similarly, attempts at weakening or reversing the associations that underlie automatic processes through cognitive bias modification (CBM) have demonstrated some success in changing both associative and health-risk behaviours across various psychopathologies (Field, Duka, Tyler, & Schoenmakers, 2009; MacLeod & Mathews, 2012), however there is currently a debate as to the overall effectiveness (see Cristea, Kok, & Cuijpers, 2015, 2016). Nevertheless, these observations have prompted the exploration of the usefulness of these types of cognitive training as tools for the modification of

unhealthy eating behaviours, in order to help people to lose weight.

2. Aims of the current review

The goal of the present paper is to critically evaluate the current cognitive training literature for food intake and associated changes in body weight, and to consider the potential of these cognitive interventions for the treatment of overweight and obesity. We focus on two main categories of training: the improvement of a reflective process or self-regulatory *capacity* (e.g. working memory capacity) and the modification of *automatic processes* through interventions based on associative learning (e.g. attentional bias training). We adopt both a systematic and narrative approach. First, we briefly discuss the evidence that each process may contribute to behaviours underlying overweight or obesity. We then use systematic searches to identify articles that attempt to modify these processes in order to explore their influence on food intake. Our review of these studies was guided by the following questions:

- i) does training influence behaviour in the laboratory i.e. does training reduce food intake, craving or choice;
- ii) does training translate to behaviour change in the 'real-world' i.e., do beneficial behavioural outcomes translate outside of the laboratory; and
- iii) is the proposed mechanism of change supported by the evidence, for example does 'capacity' training improve the relevant capacity, and does associative training change the underlying automatic processes.

Studies were included in the review if they investigated at least one of the above questions. Laboratory measures included direct observations of food intake (often during bogus 'taste tests' Robinson et al., 2017), food choice and subjective hunger/craving (Martin, O'Neil, Tollefson, Greenway, & White, 2008; Robinson, Hardman, Halford, & Jones, 2015). Outside of the laboratory, we considered self-reported food-intake or body mass index (BMI), objectively measured BMI, or trait characteristics relevant to food intake (any characteristic that has a demonstrable relationship with overweight or obesity, such as emotional eating, external eating, dietary restraint (Vandeweghe, Vervoort, Verbeke, Moens, & Braet, 2016).

3. Identification of relevant studies

We conducted a systematic literature search in November 2016. We applied the search terms (Table 1) to three widely used article databases; Scopus, PubMed and PsycInfo. Our searches identified 540 articles after removal of 90 duplicates. Following abstract and title scanning we were left with 64 full text articles. Articles were excluded if they did not train behaviour (i.e. assessment studies), or described a study protocol. We used meta-analyses and reviews to further ascertain any articles that may not have been identified by our searches. In addition to formal searches we used the reference lists of the identified articles and authors' knowledge to ensure we

had identified all relevant articles (see Fig. 1).

In total we identified 30 articles, plus 2 further articles (Adams, Lawrence, Verbruggen, & Chambers, 2017; Naomi; Kakoschke, Kemps, & Tiggemann, 2017b) from supplementary searches (conducted January 2017). These articles contributed 41 individual studies, which are summarised in Table 2. The majority of studies were conducted in laboratory settings, on predominantly female participants. Most studies only recruited female participants, for varying reasons including gender differences in craving and eating behaviours (Burton, Smit, & Lightowler, 2007), as well as cognitive performance (Havermans, Giesen, Houben, & Jansen, 2011; Nederkoorn, Baltus, Guerrieri, & Wiers, 2009). Furthermore, studies tended to recruit healthy weight individuals, rather than individuals who were exclusively overweight or obese. Finally, we did not include any studies that investigated cognitive training in clinical populations such as individuals with eating disorders. We review and synthesise the main findings for each type of training below.

4. Interventions that aim to improve the capacity of reflective processes

4.1. Generalised inhibitory control training (general-ICT)

Inhibitory control is the ability to stop, change or delay a response that is no longer appropriate (Logan, Cowan, & Davis, 1984), and is thought to be a key construct in self-regulation (Baumeister, 2014). Inhibition can be measured in the laboratory using the Stop-Signal or Go/No-Go tasks (Verbruggen & Logan, 2008), which involve overriding a pre-potent response when signalled to inhibit behaviour by an environmental cue. Laboratory evidence supports the role of inhibition in overweight and obesity. Nederkoorn, Braet, et al. (2006) and Nederkoorn, Smulders, et al. (2006) demonstrated that individuals who are obese exhibit impaired inhibitory control compared to normal weight individuals, and longitudinal research suggests that poor inhibitory control predicts subsequent weight gain and weight-status in adolescence (Anzman & Birch, 2009) and weight-loss treatment outcomes in children (Nederkoorn, Braet, et al., 2006).

The aim of general- ICT is to increase overall inhibitory control capacity, by training to often arbitrary cues. This is distinct from cue-specific ICT (described below) in which specific food-cues are paired with inhibitory responses to promote associative links between food cues and engagement of inhibitory control. We identified three studies which attempted to increase inhibitory control capacity in the laboratory. In one study, Guerrieri et al. (2012) attempted to improve inhibitory control by increasing the number of Stop Signal trials in which inhibition was required by 5% on a block-by-block basis in one group of participants ('inhibition group'), compared to a comparison ('impulsive') group in which the number of inhibition trials reduced by 5% on a block-by-block basis (eventually 0%), and a neutral control group who did not complete a Stop Signal task. Following this task, *ad-libitum* calorie-intake was assessed and a difference in subsequent food-intake was observed: participants in the impulsive group consumed more calories compared to the other two groups (however, the inhibition and control group did not differ). The authors suggested that an experimentally-induced impairment in inhibitory control results in increased food intake, but they did not directly test if this manipulation actually changed inhibitory control capacity. In a similar study, Guerrieri, Nederkoorn, Schrooten, Martijn, and Jansen (2009) provided instructions on a Stop Signal task to promote either inhibited or disinhibited responding on the task. They demonstrated an increase in successful inhibition at the expense of slowed reaction times in the inhibition group, and vice versa in the

Table 1
Search terms used for literature review.

| |
|---|
| working memory OR updat* OR inhibit* OR switch* cognit* OR executive function* OR |
| attention* bias OR associative OR approach bias |
| AND |
| modifi* OR train* |
| AND |
| food OR calories OR weight OR obese OR obesity |

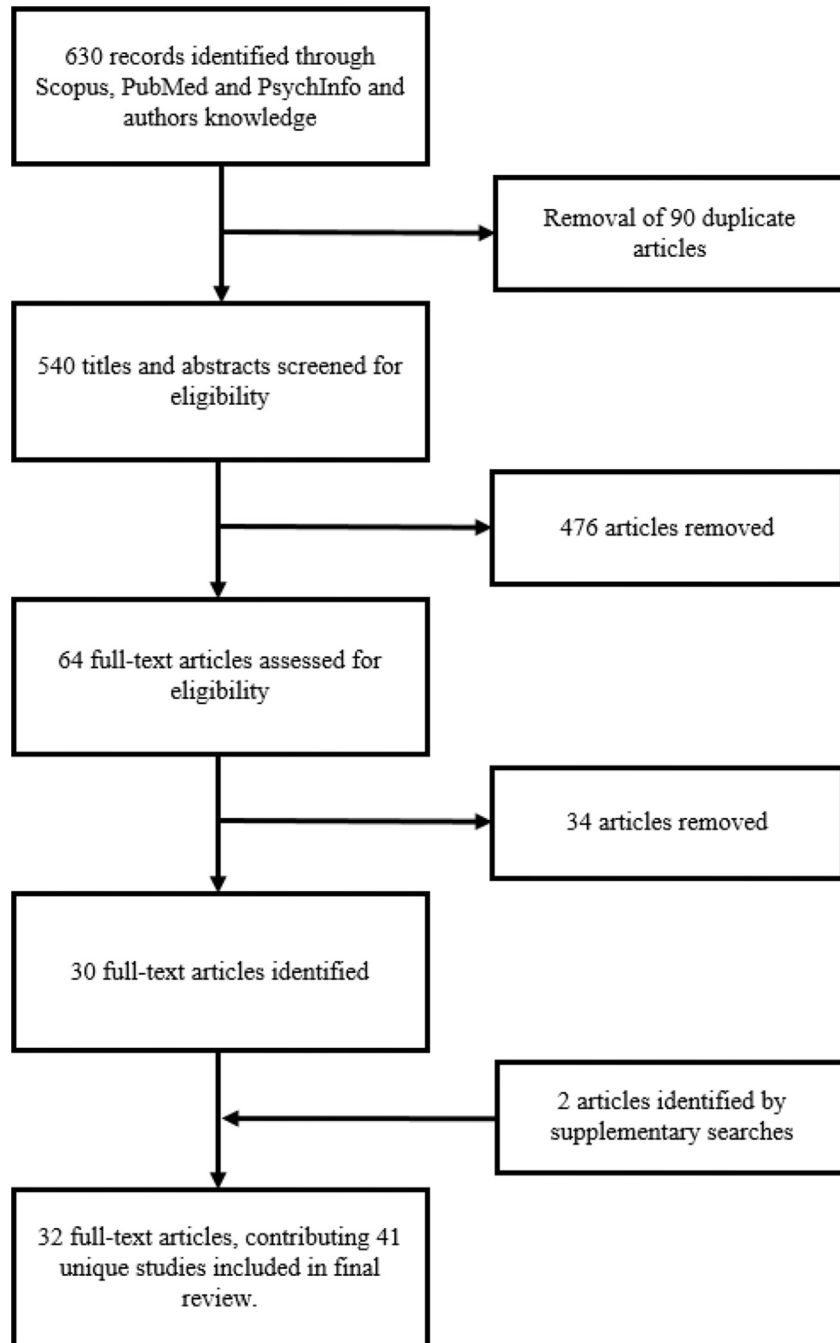


Fig. 1. PRISMA style flow chart for article identification and selection.

disinhibited group. The group in whom inhibition was prompted consumed fewer calories than the group in whom disinhibited responding was prompted, with notably larger effects in individuals who were not currently dieting. However, the lack of a control group limits the interpretation of these findings, and research in other domains suggests that the instructions used during the experimental manipulation prompt changes in disinhibited mental set rather than changes inhibitory control capacity (Jones, Cole, Goudie, & Field, 2011; Jones, Guerrieri, et al., 2011). Finally, Lawrence, O'Sullivan, et al. (2015) demonstrated no effect of non-specific inhibition training on *ad-libitum* food consumption.

The experiment consisted of three experimental groups, two training groups in which participants inhibited to neutral cues at random or inhibited to a specific category of neutral images, and a control group who were never required to inhibit their responding. Findings indicated no difference in subsequent calorie intake across the three groups ($\eta_p^2 < 0.001$), which suggest that training inhibitory control had no effect on behaviour in the laboratory. For behaviours outside of the laboratory we found no studies which examined general-ICT in isolation, but one study which examined general-ICT in combination with Working Memory Training (below).

Table 2
Details of cognitive training studies identified following the systematic literature search.

| Training | Study | Training (N) and Control (N) | Sample | Mechanism supported | Lab behaviour change | Outside behaviour change |
|---------------------|---|---|--|--|---|---|
| WMT | Houben et al. (2016) | Training (N = 24): Up to 25 sessions, increasing difficulty, via the internet Control (N = 26): Up to 25 session, same difficulty (easy), via the internet | Overweight (BMI = 31.57), males and females | Larger improvement in WM capacity from pre-post test and one month follow-up | No change in hunger or food intake from pre - post test | Reduction in eating psychopathology scales, and emotional eating No change in BMI |
| general-ICT | Guerrieri et al. (2009) | Training (Inhibition; N = ~33): One session, increasing inhibition by experimental instructions Control (Impulsivity; N = ~33): One session, increasing impulsivity by experimental instructions | Normal weight (BMI = 22.32), females | Participants in the inhibition group had a larger percentage of successful inhibitions, compared control. | Reduction in food-intake in the inhibition group, in high and low restrained non dieters, but not current dieters, compared to control/ | Not tested |
| general-ICT | Guerrieri et al. (2012) | Training (Inhibition; N = 21): One session, increasing proportion of inhibition trials Control (Neutral; N = 20): One session, read unrelated stories Control (Impulsivity; N = 20): One session, decreasing proportion of inhibition trials | Normal weight (BMI = 21.43), females | Not tested | Increased food-intake in the impulsivity group, compared to control groups. | Not tested |
| general-ICT | Lawrence, O'Sullivan, et al. (2015) Study 3 | Training (general group, N = 48): One session, inhibition to neutral cues with no association. Training (associative stop, N = 47): One session, inhibition to neutral cues with association Control (double-response group, N = 51): One session, double response to neutral cues | Normal weight (BMI = 22.94), males and females | Slowing of reaction times in the Training groups. Accuracy on Stop Signal trials greater in the associative stop training group, compared to general. | No difference in food-intake across the three experimental groups | Not tested |
| general-ICT and WMT | Verbeke et al. (2013) | Training (WMT + general-ICT + Care as usual, N = 22): 25 session, gamified training played for 40 min Control (Care as usual, N = 22): 10 month, non-diet healthy lifestyle program. | Morbidly obese children (raw BMI not reported), males and females (N = 44) | Participants in the training group had improved working memory, but not inhibition from pre-post test, compared to control | Not tested | Training group demonstrated better weight loss maintenance at 8 weeks follow-up, but not at post-test or 12 weeks follow-up, compared to control. Not tested |
| ABM | Boutelle et al. (2014) | Training (avoid food, N = 14): One session, contingency for probe behind unhealthy food word 100%. Control (control, N = 15): One session, contingency for probe behind unhealthy food word 50% | Overweight and Obese children (BMI = 26.04), males and females | No reduction in attentional bias for unhealthy foods from pre-post test in training group or control. | Reduction in eating in the absence of hunger (kcal and %) from pre-post in training group. No difference in craving or liking for foods between the two groups, or in salivary flow. | Not tested |
| ABM | Boutelle et al. (2016) | Training (avoid food, N = 9): 8 session in the clinic and at least 16 at home, contingency for probe behind unhealthy food word 0%. | Overweight and Obese adults (BMI = 33.74) | Increase in attentional bias to unhealthy foods from pre-post test as measured by visual probe task. No change in attentional bias to unhealthy foods from pre-post test as measured by Stroop. | Not tested | Reduction in binge eating episodes and scores on binge eating scale from pre-post test. Reduction in eating disorder symptoms from pre-post test. Reduction in BMI from pre-post test. Reduction in power of food scales (Available and Present) pre-post test. Reduction in Loss of control pre-port test. Not tested |
| ABM | Hardman et al. (2013) | Training (avoid food, N = 20): One session, contingency for probe behind unhealthy food cue 0% Control (attend food, N = 20): One session, contingency for probe behind unhealthy food cue 100% Control (control, N = 20): One session, contingency for probe behind unhealthy food cue 50% | Normal weight (BMI = 22.40), males and females. Participants had not eating within 2 h of study | No reduction in attentional bias in the training group. Increase in attentional bias in the control (attend) group. No change in attentional bias in the control (control) group | No change in food intake or hunger across training groups | Not tested |

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Table 2 (continued)

| Training | Study | Training (N) and Control (N) | Sample | Mechanism supported | Lab behaviour change | Outside behaviour change |
|----------|---|--|--|---|--|--------------------------|
| ABM | Kakoschke et al. (2014) | Training (attend healthy food, N = 73): One session, contingency for probe behind healthy food cue 90% Control (attend unhealthy food, N = 73): One session, contingency for probe behind healthy food cue 10% | Normal weight (BMI = 22.2), females | An increased attentional bias for healthy food cues in the training group. No change in attentional bias in the control group | Increase in proportion of healthy snack food consumed in the training group, compared to control group. | Not tested |
| ABM | Kemps et al. (2015) | Training (avoid food, N = 48): One session, contingency for probe behind high and low calorie food cue 10% Control (attend food, N = 48): One session, contingency for probe behind high and low calorie food cue 90% | Obese and normal weight (BMI = 36.63), females. Participants had eaten within two hours of study | An increased attentional bias in the control group and decreased in attentional bias in the avoid group, from pre – post test. Increased attention to food words in the training group compared to control on a word stem completion task | Not tested | Not tested |
| ABM | Kemps et al. (2014) | Training (avoid food, N = 38): One session, contingency for probe behind chocolate food cue 10% Training (avoid food, N = 35): Five sessions, contingency for probe behind chocolate food cue 10% Control (attend food, N = 37): One session, contingency for probe behind chocolate food cue 90% Control (attend food, N = 39): Five sessions, contingency for probe behind chocolate food cue 90% | Normal weight (BMI = 23.44), females with liking of chocolate | No reduction in attentional bias to chocolate in the one session training group. Reduction in attentional bias to chocolate in the five session training group at post test, 24 h and 1 week follow up. Control groups demonstrated increases in chocolate attentional bias | No change in food-consumption post test, attributable to training. Increase in specific (chocolate muffin) food-intake after 24 h and 1 week in multiple session attend group | Not tested |
| ABM | Kemps, Tiggemann, Orr, et al. (2014; Study 1) | Training (avoid food, N = 55): One session, contingency for probe behind chocolate food cue 10% Control (attend food, N = 55): One session, contingency for probe behind chocolate food cue 90% | Weight not stated, females with liking of chocolate | Reduction in attentional bias in the training group from pre-post test. Increase in attentional bias in the control group from pre-post test. | Decrease in specific (chocolate muffin) food-intake in the training group No change in craving between groups | Not tested |
| ABM | Kemps, Tiggemann, Orr, et al. (2014; Study 2) | Training (avoid food, N = 44): One session, contingency for probe behind chocolate food cue 10% Control (attend food, N = 44): One session, contingency for probe behind chocolate food cue 90% | Weight not stated, females with liking of chocolate | Reduction in attentional bias in the training group from pre-post test. Increase in attentional bias in the control group from pre-post test. | Decrease in specific (chocolate muffin) food-intake in the training group. Decrease in craving from pre-post test in the training group. Increase in craving from pre = post test in the control group | Not tested |
| ABM | Kemps et al. (2016) | Training (avoid food, N = 52): Five sessions, contingency for probe behind food cue 10% Control (attend food, N = 52): Five sessions, contingency for probe behind food cue 90% | Overweight and Obese (BMI = 34.43), females | Reduction in attentional bias in the training group at post-test, 24 h follow-up and 1 week follow-up. Control group demonstrated increase in attentional bias at all follow-ups No effects of group on word stem completion at any time points | Not tested | Not tested |

| | | | | | | |
|---------|--------------------------------------|---|--|--|--|--|
| ABM | Werthmann et al. (2014) ^a | Training (Attend shoes, N = 26): One session, contingency for chocolate anti-saccade 100% Control (Attend chocolate, N = 25): One session, contingency for chocolate anti-saccade 0% | Normal weight (BMI = 22.12), females | Decreased attention to chocolate cues in the training group compared to control, as measured by eye-movements. | A reduction in ad-libitum chocolate consumption and hunger in the training group compared to control. No difference in craving or amount of time spent searching for chocolate between groups | Not tested |
| cue-ICT | Adams et al. (2017) Study 1 | Training (stop group, N = 71): One session, contingency for inhibition to food 87.5% Control (double-response group, N = 72): One session, instead of inhibiting to food cues a double-response was required | Normal weight (BMI = 24.53), males and females. Restrained, chocolate craving individuals | Effects of associative inhibition not tested. No change in devaluation of food-cues | Increase in food-intake in the training group | Not tested |
| cue-ICT | Adams et al. (2017) Study 2 | Training (stop group, N = 46): One session, contingency for inhibition to food 88.9% Training (No-Go group, N = 35): One session, contingency for inhibition 100% Control (double-response group, N = 49): One session, instead of inhibiting to food cues a double response was required Control (go group, N = 35): One session, contingency for inhibition to food 0% Control (observation group, N = 32): One session, viewing food and non-food images | Normal weight (BMI = 24.26) males and females. Restrained eaters | Not reported | Reduction in unhealthy food intake in training groups, compared to double-response and go groups. Increase in unhealthy good intake in go group compared to observation group | Not tested |
| cue-ICT | Allom and Mullan (2015) Study 1 | Training (food-specific, N = 29): Ten sessions, contingency for inhibition to unhealthy food 100% Control (general inhibition, N = 25): Ten sessions, contingency for inhibition to unhealthy food 50% Control (no inhibition, N = 28): Ten sessions, contingency for inhibition to unhealthy food 0% | Normal weight (BMI = 22.62), females. Intention to change dietary behaviour | Effects of associative inhibition not tested. No change in Stroop performance from pre-post test | Not tested | Subjective BMI reduced in the training group, compared to control groups, from –pre-post test No change in saturated fat intake. |
| cue-ICT | Allom and Mullan (2015) Study 2 | Training (food-specific, N = 27): Ten sessions, contingency for inhibition to unhealthy food 100% Control (general inhibition, N = 26): Ten sessions, contingency for inhibition to unhealthy food 50% Control (no inhibition, N = 25): Ten sessions, contingency for inhibition to unhealthy food 0% | Normal weight (BMI = 23.11), females. Intention to change dietary behaviour | Effects of associative inhibition not tested. Improvement in Stroop performance improved in training and general inhibition group compared to no inhibition group, from pre-post test | Not tested | No difference in objective BMI in experimental groups, from pre-post test or one week follow-up No change in energy from fat in experimental groups |
| cue-ICT | Houben et al. (2011) | Training (No-Go group, N = 24): One session, contingency for inhibition to chocolate 100% Control (Control group, N = 22): One session, contingency for inhibition to chocolate 50% Control (Go group, N = 23): One session, contingency for inhibition to chocolate 0% | Normal weight (BMI = 22.39), females. Chocolate cravers. Participants had not eating within 2 h of study | Not reported | Reduction in food-intake in the training group compared to both control groups. | Not tested |
| cue-ICT | Houben and Jansen (2015) | Training (No-Go group, N = 26): One session, contingency for inhibition to chocolate 100% Control (Go group, N = 26): One session, contingency for inhibition to chocolate 0% | Normal weight (BMI = 22.18), females. Participants had not eating within 2 h of study | Increase in food-stop associations in the training group | Reduction of unhealthy food-intake in the training group compared to control. Reduction of the desire to eat in the training group, compared to control. | Not tested |
| cue-ICT | Blackburne et al. (2016) | Training (No-Go, N = 29): 140 sessions, contingency for inhibition to food varied randomly 10–30% Control: (Wait-list, N = 29): Received access to intervention after assessment period | Overweight/obese (BMI = 29.54), males and females. | Participants in the training group got faster and made less inhibition errors over tie. | Decrease in ad-libitum food intake for unhealthy food in the training group from pre-post test. Increase in ad-libitum food intake for healthy food in the training group from pre-post test | Significant increase in healthy food consumption in the training group. Significant decrease in healthy food in the wait-list group. |

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Table 2 (continued)

| Training | Study | Training (N) and Control (N) | Sample | Mechanism supported | Lab behaviour change | Outside behaviour change |
|----------|---|---|--|---|---|---|
| cue-ICT | Folkvord et al. (2016) | Training (No-Go + food adverggame, N = 36): One session, contingency for inhibition to candy 100% Training (No-Go + non-food adverggame, N = 32): One session, contingency for inhibition to candy 100% Control (Control and food adverggame, N = 33): One session, contingency for inhibition to candy 0% Control (Control and non-food adverggame, N = 32): One session, contingency for inhibition to candy 0% | Normal weight children (BMI = 17.48), males and females. | Not tested | No change in the wait-list control. Decrease in ad-libitum food intake for unhealthy food in the training groups, compared to the control groups. No interaction with adverggame manipulation | Not tested. |
| cue-ICT | Lawrence, O'Sullivan, et al. (2015) Study 1 | Training (stop group, N = 29): One session, contingency for inhibition to unhealthy food 87.5% Control (double-response group, N = 24): One session, instead of inhibiting to food cues a double-response was required | Normal weight (BMI = 22.9), males and females | Not tested | Decreased food intake in the training group, compared to control | Not tested |
| cue-ICT | Lawrence, O'Sullivan, et al. (2015) Study 2 | Training (stop group, N = 44): One session, contingency for inhibition to unhealthy food 87.5% Control (double-response group, N = 46): One session, instead of inhibiting to food cues a double-response was required Control (ignore group, N = 46): One session, single response to all cues required | Normal weight (BMI = 23.50), males and females | Not tested | No differences in food-intake between groups. | Not tested |
| cue-ICT | Lawrence, Verbruggen, Morrison, Adams, and Chambers (2015b) | Training (active, N = 41): Four sessions, contingency for inhibition to unhealthy food 100% Control (control, N = 42): Four sessions, contingency for inhibition to unhealthy food 0%. | Overweight and Obese (BMI = 28.89), males and females | No-go error rates improved over time in both groups. Reductions in food evaluations in the training group. Reductions in liking of high-energy dense foods in the training group from pre-post, no change in the control group. | No differences in food-intake between groups | Reduced objective weight in the training group at post-test. No difference in subjective weight at one-month follow up, but reductions at six month follow-up in training group. No differences between groups on snacking frequency across all time points. Reduction in energy intake in the training group during from pre-post test, but not in control. Not tested |
| cue-ICT | Van Koningsbruggen et al. (2014) Study 1 | Training (GNG + II, N = 23), One session, contingency for inhibition to unhealthy food 100% and II formation. Training (GNG + II control, N = 24), One session, contingency for inhibition to unhealthy food 100% and no-relevant II formation. Training (GNGC + II, N = 20), One session, contingency for inhibition to unhealthy food 0% and II formation. Control (GNGC + II control, N = 24), One session, contingency for inhibition to unhealthy food 0% and no-relevant II formation. | Normal weight (BMI = 22.08), males and females | Not reported | Decreased self-serving of sweets in the training groups, compared to control. | Not tested |

| | | | | | | |
|---------|-----------------------------------|---|---|--|---|--|
| cue-ICT | Van Koningsbruggen (2014) Study 2 | Training (GNG + II, N = 20), One session, contingency for inhibition to unhealthy food 100% and II formation. Training (GNG + II control, N = 24), One session, contingency for inhibition to unhealthy food 100% and no-relevant II formation. Training (GNGC + II, N = 23), One session, contingency for inhibition to unhealthy food 0% and II formation. Control (GNGC + II control, N = 22), One session, contingency for inhibition to unhealthy food 0% and no-relevant II formation. | Normal weight (BMI = 21.17), males and females | Not reported | Decreased self-serving of sweets in the training groups, compared to control. | Not tested |
| cue-ICT | Veling et al. (2011) Study 2 | Training (no – go, N = 23): One session, contingency for inhibition to unhealthy food 100% Control (go, N = 23). One session, contingency for inhibition to food 0% | Normal weight (BMI = 21.54), males and females | Not reported | Not tested | No difference in sweets consumed outside of the laboratory between groups. A significant interaction with chronic dieting. |
| cue-ICT | Veling et al. (2013) Study 1 | Training (no – go, N = 40): One session, contingency for inhibition to unhealthy food 100% Control (go, N = 39). One session, contingency for inhibition to unhealthy food 0% | Normal weight (BMI = 22.00), males and females. | Not reported | Reduced unhealthy food choices in the training group. Interaction with appetite | Not tested |
| cue-ICT | Veling et al. (2013) Study 2 | Training (no – go, N = 22): One session, contingency for inhibition to unhealthy food 100% Control (go, N = 22). One session, contingency for inhibition to unhealthy food 0% | Normal weight (BMI = 21.61). | Not reported | Reduced unhealthy food choices in the training group. Interaction with past behaviour | Not tested |
| cue-ICT | Veling et al. (2014) | Training (GNG + II, N = 25), Four sessions, contingency for inhibition to unhealthy food 100% and II formation. Training (GNG + IIC, N = 29), Four sessions, contingency for inhibition to unhealthy food 100% and no-relevant II formation. Training (GNGC + II, N = 33), Four sessions, contingency for inhibition to unhealthy food 0% and II formation. Control (GNGC + IIC, N = 26), Four sessions, contingency for inhibition to unhealthy food 0% and no-relevant II formation | Normal weight (BMI = 24.4), males and females | Not reported | Not reported | Reduction in objective weight measured in the training groups compared to control. |
| cue-ICT | Forman et al. (2016) | Training (ICT, N = 27): Four sessions, contingency for inhibition to food not reported Training (ICT + MDT, N = 22): Four sessions, contingency for inhibition to food not reported, prompts to think about mindful decision making Training (MDT, N = 27): Four sessions, prompts to think about mindful decision making Control (Psychoed, N = 27): One session, information on food labels and unhealthy eating | Normal weight (BMI = 24.45), males and females. A desire to reduce snack food consumption reported | Not reported | Not reported | No reduction in salty snack food consumption in training (ICT) groups. Interaction with emotional eating. |
| AAT | Becker et al. (2015) Study 1 | Training (AAT, N = 26): One session, contingency for avoiding unhealthy food 90% Control (sham, N = 25): One session, contingency for avoiding unhealthy food 50% | Normal weight (BMI = 21.57), males and females | No reduction in food approach bias in the training group from pre-post. No change in food approach bias in the control group. | Snack food choices did not differ between groups | No difference at two week follow up in fruit consumption or frequency of sport playing. Reduced ready meal consumption in the training group |

(continued on next page)

Table 2 (continued)

| Training | Study | Training (N) and Control (N) | Sample | Mechanism supported | Lab behaviour change | Outside behaviour change |
|-----------------|------------------------------|---|---|--|--|--|
| AAT | Becker et al. (2015) Study 2 | Training (AAT, N = 52): One session, contingency for avoiding unhealthy food 90% Control (sham, N = 52): One session, contingency for avoiding unhealthy food 50% | Normal weight (BMI = 21.01), males and females | No reduction in food approach bias in the training group from pre-post. No change in food approach bias in the control group. | Healthy food choices did not differ between groups. Wanting and liking ratings did not differ between groups | Not tested |
| AAT | Becker et al. (2015) Study 3 | Training (AAT, N = 52): One session, contingency for avoiding unhealthy food 90% Control (sham, N = 51): One session, contingency for avoiding unhealthy food 50% | Normal weight (BMI = 22.04), males and females. Intentions to reduce chocolate intake. | No reduction in food approach bias in the training group from pre-post. No change in food approach bias in the control group. | Increased food consumption in the training group, compared to control. | Not tested |
| AAT | Brockmeyer et al. (2015) | Training (avoid food, N = 30): Ten sessions, contingency to avoid food 100%. No control group | Normal weight (BMI = 24.08), females. High levels of self-reported trait food craving | Reductions in approach to food from pre-post test. | Reduced food craving after cue exposure from pre-post test. | Reduced trait food craving from pre-post test. Reduced eating disorder symptoms from pre-post test. |
| AAT | Dickson et al. (2016) | Training (avoid chocolate, N = 45): One session, contingency for avoiding chocolate 90%. Control (approach chocolate, N = 45): One session, contingency for avoiding chocolate 10%. | Weight not reported, males and females Not dieters | Training group had significant reduction in approach to chocolate. | No difference between groups on food consumption No change in craving from pre-post between groups. | Not tested |
| AAT and cue-ICT | Kakoschke et al. (2017b) | Training (AAT training + GNG training, N ~ 60): One session, contingency to avoid unhealthy food 90% and to inhibition to unhealthy food 90%. Training (AAT training + GNG control, N ~ 60): One session, contingency to avoid unhealthy food 90% and to inhibition to unhealthy food 50%. Training (AAT control + GNG training, N ~ 60): One session, contingency to avoid unhealthy food 50% and to inhibition to unhealthy food 90%. Control (AAT control + GNG control, N ~ 60): One session, contingency to avoid unhealthy food 50% and to inhibition to unhealthy food 50%. | Normal weight (BMI = 22.91), females. Participants had eaten within two hours of study | Increases in avoidance to unhealthy foods in the AAT training groups. No increases in inhibitory control in GNG training groups Combined training had reduced food evaluations compared to single training and control group | No difference between groups on food consumption. Increased healthy food choice in AAT training | Not tested |
| AAT | Kemps et al. (2013) | Training (avoid, N ~ 48): One session, contingency to pair chocolate pictures with avoid 90% Control (approach, N ~ 48): One session, contingency to pair chocolate pictures with approach 10% | Normal weight (BMI not reported), females. Participants had eaten within two hours of study | Significant decrease in approach bias scores from pre-post test in training group. Significant increase in approach bias scores from pre-post test in control group | No decrease in chocolate craving from pre-post test in the training group. Increase in chocolate craving from pre-post test in the control group. | Not tested |
| AAT | Schumacher et al. (2016) | Training (avoid chocolate, N ~60): One session, contingency to avoid food 90%. Control (approach chocolate N ~60): One session, contingency to avoid chocolate 10% | Normal weight (BMI = 23.00), females. | Increased avoidance to food cues in the training group from pre-post test. | Participants consumed significantly less of the (specific) food in the training group than control | Not tested |

Legend: AAT = Approach/Avoidance Training; ABM = Attentional Bias Modification; BMI = Body Mass Index; GNG = Go/No-Go training; ICT = Inhibitory Control Training; II = Implementation Intentions; MDT = Mindful Decision Making Training; WMT = Working Memory Training.

^a Note, this study used a task used to measure Inhibitory Control Task (anti-saccade) to train attention so there is some overlap with a-ICT paradigms.

4.2. Working Memory Training (WMT)

Working memory is the ability to retain information in consciousness and make it readily accessible, whilst allowing for prioritisation, updating and removal (see Bickel, Moody, & Quisenberry, 2014; Bledowski, Kaiser, & Rahm, 2010). This ability plays a key role in maintaining active self-regulation and goal-directed behaviour, for example keeping a weight-loss goal in mind when faced with temptation ('goal-shielding'; Hofmann, Friese, Schmeichel, & Baddeley, 2011). In the laboratory, working memory can be assessed using tasks such as the (backward) digit/letter span task(s) and the n-back task (Diamond, 2013). Again, laboratory evidence implies a role for working memory in overweight and obesity as these groups have impaired working memory capacity (Alarcón, Ray, & Nagel, 2016), and working memory predicts the likelihood of being overweight in the future in adolescents (Stautz, Pechey, Couturier, Deary, & Marteau, 2016).

WMT has shown promise across different psychopathologies for a range of symptoms (Klingberg, 2010), including the field of addiction (Bickel et al., 2014; Houben, Wiers, & Jansen, 2011), however there have been few attempts to translate WMT to overweight and obesity either inside or outside of the laboratory. One study (Houben, Dassen, & Jansen, 2016), randomised overweight and obese individuals to WMT or a control group. Participants in the WMT group completed 3 working memory tasks per day outside of the laboratory via the internet, that become increasingly difficult on a trial-by-trial basis. The control group completed the same tasks at the same (easy) difficulty each session. Each group could complete up to 25 sessions of training overall. Following the intervention period, both groups demonstrated improvements in working memory capacity although, critically, the magnitude of this improvement was significantly larger in the active WMT group ($\eta_p^2 = 0.11$). The training group also demonstrated reductions in emotional eating and eating psychopathology, but no reductions in *ad-libitum* food intake, craving or hunger in the laboratory, or BMI.

Outside of the laboratory, one study combined WMT and general-ICT, in obese children (Verbeken, Braet, Goossens, & van der Oord, 2013) and they 'gamified' training in an attempt to optimise participant engagement (Lumsden, Skinner, Woods, Lawrence, & Munafò, 2016). Participants were randomised to care-as-usual or to care-as-usual combined with cognitive training which involved 25 sessions over a six week period. If participants' performance on the training game improved this led to improvements in the game character and elaborated game world. At post-test, working memory but not inhibitory control was improved in all participants in the training group; however there was no evidence of change in the control group. Both groups lost similar amounts of weight at post-test, which was maintained at 8 week follow-up in the training group only, although this effect disappeared at a 12-week follow up. Given the improvement in working memory in the training group this seems to be the 'active' mechanism (rather than an improvement in inhibitory control), however in the absence of formal mediation analyses these findings should be interpreted with caution.

4.3. Interim summary of capacity driven training

Examination of the evidence for capacity driven training suggests limited potential for general-ICT for treatment of overweight and obesity, with the evidence difficult to reconcile due to a lack of robust change in the reflective process (inhibitory control capacity). This is consistent with findings from related areas in which general-ICT has demonstrated minimal effects on behaviour change, including alcohol-use (Bartsch, Kothe, Allom, Mullan, & Houben,

2016) and gambling (Verbruggen et al., 2013). However two studies have demonstrated initial promise for WMT which may both increase WM capacity and prompt changes in eating behaviour outside of the laboratory. Future studies should attempt to replicate and extend these findings.

5. Interventions that aim to change associations that underlie automatic processes

5.1. Attentional bias modification (ABM)

Attentional bias is the tendency for specific stimuli to capture the attention (Field et al., 2016). Attentional biases for high-caloric foods are correlated with craving and hunger (Hardman, Scott, Field, & Jones, 2014; Werthmann, Roefs, Nederkoorn, & Jansen, 2013), and they may distinguish between normal weight, overweight and obese individuals (Castellanos et al., 2009), although this is disputed (Field et al., 2016; Werthmann, Jansen, & Roefs, 2015). Attentional biases may also predict individual differences in subsequent weight gain longitudinally (Yokum, Ng, & Stice, 2011). For in depth reviews of attentional bias in overweight and obesity we point readers elsewhere (Field et al., 2016; Hendrikse et al., 2015; Werthmann et al., 2015). Attentional biases are often measured using Visual Probe tasks (MacLeod, Mathews, & Tata, 1986), in which participants have to make speeded responses to visual probes that appear in the spatial location that had been occupied by food-related or 'control' images.

ABM was originally developed to examine the causal influence of attentional bias for threat-related cues on emotional vulnerability (see MacLeod, Rutherford, Campbell, Ebsworthy, & Holker, 2002), and it was subsequently expanded to other behaviours including alcohol-intake (Field & Eastwood, 2005), and smoking (Kerst & Waters, 2014). ABM works by training attention away from the appetitive or maladaptive cues and towards neutral/control alternatives. In order to do this, the probe almost always (usually 90–100% of the time) appears in the spatial location previously occupied by the neutral/control cue-type, so that the participant should learn an association between food-related cues and the likely location of probes, and therefore learn to direct their attention away from the food-cues (typically referred to as an 'avoid food' group). By contrast, in 'attend food' groups, the probe almost always appears in the spatial location that been previously occupied by food-related cues, which should prompt participants to direct their attention towards food-related cues.

Several studies contrasted the effects of 'attend' and 'avoid' food groups on various outcome measures in the laboratory including *ad-libitum* food intake (Kemps, Tiggemann, & Elford, 2015; Kemps, Tiggemann, & Hollitt, 2014; Kemps, Tiggemann, Orr, & Grear, 2014). Most reported differences between groups in the hypothesised direction, i.e. participants allocated to 'avoid food' groups consumed less of that food than participants allocated to 'attend food' groups, with a meta-analysis of a small number of studies demonstrating a significant effect of reduced unhealthy food intake with a moderate effect size ($k = 4$; $d = 0.51$; Turton, Bruidegom, Cardi, Hirsch, & Treasure, 2016). However, these studies provide no support for the idea that reducing the associative link between attentional bias and food reduces food intake, because a lack of appropriate control group (in which attention is not manipulated) makes the findings difficult to interpret. For example, within-subjects contrasts demonstrate that, in children, a single session of ABM had no effect on eating in the absence of hunger over time; however a comparison group increased eating in the absence of hunger, despite no change in attentional bias in either group (Boutelle, Kuckertz, Carlson, & Amir, 2014). In adults the effects of repeated ABM may be driven by control/comparison groups rather

than a reduction in food intake after 'avoid food' manipulations (Kemps, Tiggemann, & Elford, 2015). Indeed, one study which did include a control group demonstrated only weak evidence for an increase in attentional bias to food in the 'attend food' group, but no change in the 'avoid food' group, and no between-group differences in food intake (Hardman, Rogers, Etchells, Houstoun, & Munafò, 2013).

Outside of the laboratory, Boutelle, Monreal, Strong, and Amir (2016) conducted a small open-label trial to examine the feasibility of 'avoid food' ABM for binge eating, in overweight and obese individuals. Participants completed multiple sessions of 'avoid food' training, which consisted of one lab-based session and two at home per week, for 8 weeks. At post-treatment there were significant reductions in binge eating (scores and episodes), eating disorder symptoms, scores on power of food subscales and BMI, with some effects remaining at 3 month follow-up. Despite these beneficial effects on eating behaviour, authors also reported that attentional bias to food actually *increased* following training. Furthermore, as with the majority of the laboratory investigations any results from this study should be interpreted with caution due to the lack of a control/comparison group.

With regards to mechanisms, ABM has been shown to reduce attentional bias to food-related cues from pre-to-post training in the laboratory and also after follow-ups of various delays, usually between 24 h and one week (Kemps, Tiggemann, & Elford, 2015; Kemps, Tiggemann, & Hollitt, 2016), although this is not always seen (Boutelle et al. 2016). Notably, the opposite effect is usually observed in 'food-attend' control groups in that attentional bias to food increases, which may be problematic (see limitations). To our knowledge nobody has directly investigated whether changes in attentional bias following training influences subsequent eating-related behaviours.

5.2. Cue-specific inhibitory control training (cue-ICT)

Whereas the goal of general-ICT is to increase inhibitory control capacity, the goal of cue-specific ICT (cue-ICT) is to teach participants to form associations between food-related cues and the engagement of inhibitory control, without improving the general capacity to inhibit behaviour *per se*. The rationale is that, with repeated training, food-related cues may evoke inhibition of behaviour automatically, and thereby prompt a reduction in food intake (Stice, Lawrence, Kemps, & Veling, 2016). To establish food-inhibition associations, food-related and neutral cues are embedded into an inhibitory control task and the signal to inhibit is disproportionately paired with food-related cues: as with ABM this contingency is usually around 90%–100%. For simplicity we label any study which trains inhibition to food cues (rather than neutral) cues as cue-ICT, however we note considerable variation in cue-ICT paradigms (see Table 2), and different tasks used which are likely to influence associative learning, and the effects on behaviour (see Jones et al., 2016).

Dual process models suggest that appetitive cues spontaneously provoke an *approach* response (Kemps & Tiggemann, 2015), which may impair the ability to control behaviour when these cues are encountered. Laboratory research supports this view: both healthy (Meule, Lutz, Krawietz, Stützer, Vögele, & Kübler, 2014) and overweight (Batterink, Yokum, & Stice, 2010; Houben, Nederkoorn, & Jansen, 2014) participants are less able to inhibit their responses during exposure to high-caloric food images compared to during exposure to control images or low calorie food images. Furthermore, food-specific inhibitory control impairments are associated with craving for high-calorie foods (Meule, Lutz, Vögele, & Kübler, 2014), and BMI (Batterink et al., 2010; Houben et al., 2014).

The evidence for an influence of a brief session of cue-ICT on

behaviour change in the laboratory is relatively robust. Individual studies have demonstrated reductions in *ad-libitum* food intake and choice across a number of studies in adults (Houben, 2011; Houben & Jansen, 2015; Lawrence, Verbruggen, Morrison, Adams, & Chambers et al., 2015; Van Koningsbruggen, Veling, Stroebe, & Aarts, 2014; Veling, Aarts, & Stroebe, 2013), and children (Folkvord, Veling, & Hoeken, 2016). Three published meta-analyses have confirmed these effects and demonstrate an overall small to moderate sized effect ($d \sim 0.33$; Allom, Mullan, & Hagger, 2015; Jones et al., 2016; Turton et al., 2016) of cue-ICT on food intake and choice in the laboratory. However, more recent findings in which Bayesian inference has demonstrated evidence in favour of null hypothesis for food-intake have been published (Adams et al., 2017; Study 1).

Outside of the laboratory, Forman et al. (2016) implemented Ecological Momentary Assessment to examine food-intake, following a single session of laboratory-based cue-ICT. They demonstrated no evidence for reductions in snack intake in the real-world following cue-ICT compared to mindfulness training or an active control (psychoeducation – information and training on food labels and risks of unhealthy foods). However, a limited number of food-inhibition pairings (the training group had to approach food, more than inhibit) may not have led to strong food-inhibition associations and thus reduced the likelihood of behaviour change (see below and Jones et al., 2016). Several studies have also examined whether *repeated* cue-ICT administered outside of the laboratory can influence behaviour. Veling, van Koningsbruggen, Aarts, & Stroebe et al. (2014) administered 4 training sessions over a 4 week period in healthy weight individuals and demonstrated significant reductions in weight over the training period, compared to a control group which inhibited and responded to images unrelated to food (e.g. knots). Lawrence, O'Sullivan, et al. (2015) examined repeated training over one week (up to four sessions) using similar methods in overweight individuals and demonstrated reductions in weight and also energy intake, which persisted up to 6 months (however participants were no longer blinded to group allocation and provided a subjective weight recording at this follow-up). In two further studies which administered repeated sessions of cue-ICT online, evidence was divergent. In Allom and Mullan (2015) study 1, individuals who intended to change their diet demonstrated significant reductions in self-reported BMI (-0.35) over 12 days in an cue-ICT group but not a group in which inhibition was not associated with food cues or a no-inhibition control group (discussed above). However, when this experiment was replicated using an objective measure of BMI the effects did not replicate (Allom & Mullan, 2015; study 2). Finally, Blackburne, Rodriguez, and Johnstone (2016) gamified cue-ICT in a pilot experiment using a smartphone device in overweight/obese individuals, in which inhibition was trained to unhealthy food and approach was trained to healthy foods, over several short sessions. They demonstrated no changes in laboratory assessments of food intake (*ad-libitum* consumption) but significant increases in self-reported frequency of healthy food consumption compared to a wait-list control.

To examine changes in food-inhibition associations as a mechanism Houben and Jansen (2015) trained participants to inhibit to chocolate cues compared to neutral cues. They then measured speed of responding when chocolate was paired with stop images (i.e. a red traffic light), compared to go images (i.e. a green traffic light) and demonstrated faster pairings of chocolate and stop following cue-ICT. In support of this, a significant relationship between the accuracy of inhibition to appetitive cues and the effect size of cue-ICT on behaviour change in the laboratory (Jones et al., 2016), supports the formation of food-inhibition responses as a mechanism of behaviour change. Importantly, this may help shed

some light onto the conflicting evidence across a-ICT studies as many have only a small number of potential food-inhibition pairings (~25%; Allom & Mullan, 2015; Forman et al., 2016). This small percentage means in these studies individuals also have to 'go' to food often as much (if not more) than to inhibit, which may not be strong enough to influence associative learning (Verbruggen et al., 2014). The formation of food-inhibition associations as a potential mechanism of cue-ICT, and the optimal conditions by which these associations develop, has been highlighted by recent reviews (see Stice et al., 2016; Veling, Lawrence, Chen, van Koningsbruggen, & Holland, 2017).

These reviews also suggest other mechanisms which may contribute to behaviour change in combination with food-inhibition associations, or in isolation. One mechanism is the change in stimulus evaluations. Associative pairings between appetitive cues and inhibition are thought to create a response-conflict, and participants overcome this conflict by devaluing the appetitive cues (Chen, Veling, Dijksterhuis, & Holland, 2016; Veling et al., 2013; Veling, Holland, & van Knippenberg, 2008), however this is not always observed (Jones et al., 2016). Furthermore, pilot data reported in Stice et al. (2016) demonstrated that repeated cue-ICT reduced attentional bias to high calorie foods, caused a devaluation of these foods and stronger respond-signal learning. Nevertheless, more research is needed and further identification of the precise mechanisms for cue-ICT is essential going forward.

5.3. Approach and avoidance training (AAT)

As discussed in the previous section, automatic approach responses contribute to the impulsive system. Automatic approach responses are measured using the Approach and Avoidance Task, amongst others. In this task participants make avoidance movements to cues, often by pushing a joystick away from the body, or approach movements by pulling the joystick towards the body. This, combined with zooming animations on the screen emphasizes the sensation of approaching or avoiding, respectively (Stacy & Wiers, 2010). There is evidence to suggest approach biases evoked by food-related cues are associated with craving for desirable food (Kemps, Tiggemann, Martin, & Elliott, 2013) and can be used to distinguish overweight and obese from healthy weight individuals (Kemps & Tiggemann, 2015), although this is not always the case (Havermans et al., 2011).

As with other methods of associative training, modified versions of assessment tasks can be used to change behaviour by biasing contingencies to establish an associative link between approach/avoidance and food. Studies examining behaviour change in the laboratory following AAT have demonstrated inconsistent results. Schumacher, Kemps, and Tiggemann (2016) demonstrated a reduction in unhealthy food consumption following 'avoid' training ($d = 0.37$), whereas Becker, Jostmann, Wiers, and Holland (2015) demonstrated no reliable change in food choice following training across three studies. Dickson, Kavanagh, and MacLeod (2016) also demonstrated no group differences between 'avoid chocolate' training and 'approach healthy snack' control on *ad libitum* chocolate intake ($\eta_p^2 = 0.024$). In a conceptually similar study, Kemps et al. (2013) aimed to establish associative links between unhealthy (chocolate) pictures and approach or avoid words, (rather than overt approach or avoidance behaviours). They demonstrated a decrease in chocolate-approach associations in the avoid group, but no decrease in craving. They did report an increase in chocolate approach associations and craving in the approach group. Finally one study (Kakoschke et al., 2017b) examined cue-ICT and AAT in combination or alone and demonstrated that neither training influenced food intake, but avoidance training reduced unhealthy food choices. However, as with many CBM

laboratory studies these results are difficult to interpret due to the absence of an appropriate 'neutral' control/comparison group. For a broader review on AAT across different appetitive behaviours in the laboratory we point readers elsewhere (Kakoschke, Kemps, & Tiggemann, 2017a).

Single sessions of AAT also have limited effectiveness on behaviour outside of the laboratory. Becker et al. (study 1) followed up participants in their training study after 2 weeks by asking about frequency of health behaviours (e.g. consumption of fruit/ready meals). Their analyses revealed a large reduction ($d = 0.99$) in self-reported consumption of ready meals in the 'avoid' training group but no effect on the frequency of other health behaviours, notably participants in the control group avoided equal numbers of healthy and unhealthy images. One uncontrolled phase II trial (Brockmeyer, Hahn, Reetz, Schmidt, & Friederich, 2015) examined the effects of 10 sessions of approach/avoidance training to food-related images, which took place over a 5 week period. They demonstrated a reduction in food approach bias following training that were accompanied by reductions in state and trait food craving, and eating disorder symptoms. Whilst these findings are promising, there was no control group. Furthermore, the reported non-significant association between change in approach bias following training and behavioural outcome measures suggests that a change in approach behaviours was not the 'active' mechanism. Nevertheless, avoidance training interventions in the addiction literature demonstrate long term behaviour change (up to one year) in the reduction of relapse to drinking after treatment, which are mediated by the change in approach-avoidance associations (Wiers, Eberl, Rinck, Becker, & Lindenmeyer, 2011).

Regarding the question of whether avoidance training establishes robust associations between food and avoidance, the evidence is equivocal. Following avoidance training, Schumacher et al. (2016) demonstrated a robust increase in avoidance to chocolate images compared to matched sweet non-chocolate foods (i.e. vanilla cake), whereas Dickson et al. (2016) demonstrated a robust decrease in the speed of approach to chocolate images, compared to healthy snacks (e.g. fruit). However, Becker et al. (2015) failed to demonstrate a significant change in the approach/avoidance bias scores following avoidance training in three separate laboratory studies. Notably, whilst each of these studies used an 'avoid food' training group, there were differences in the contingencies between food pictures and the requirement to approach in the control groups (90% vs 50%) which may contribute to the inconsistent findings.

5.4. Interim summary of associative training

The majority of cognitive training for food approach behaviours has attempted to establish associations between food and attentional or behavioural avoidance, or inhibitory control, with each type of training (ABM, cue-ICT, AAT) demonstrating some degree of success in influencing food intake or choice in the laboratory. However more recent findings suggest no effect or even detrimental effects of these interventions (Becker et al., 2015). Outside of the laboratory, repeated cue-ICT has prompted reductions in weight and emotional eating, although some of these effects may be reliant on subjective measurements which have associated biases (Polivy, Herman, Trottier, & Sidhu, 2014), however it is worth noting that Lawrence, O'Sullivan, et al. (2015) and Veling, van Koningsbruggen, Aarts, and Stroebe (2014) found promising effects in objective measures of BMI and weight. Finally, the interpretation of multiple session AAT and ABM studies are complicated by the absence of 'no training' control groups, which we discuss in more detail below.

6. Evaluation and synthesis

In this review we distinguished two broad types of cognitive training: those that aim to improve the *capacity* of reflective or controlled processes (general-ICT and WMT) versus those that aim to alter the automatic processes that are engaged in response to food-related cues (ABM, cue-ICT, AAT). Cognitive training has received increased attention as a potential treatment for overweight and obesity, due to varying success of current approaches to weight-loss (Michie, Abraham, Whittington, McAteer, & Gupta, 2009), and a number of possible advantages over traditional behaviour change interventions. Cognitive training can be administered via a computer or portable device which overcomes practical barriers to traditional treatments such as referral to open-group behavioural interventions (Gupta, 2014), but also the need for face-to-face time with a healthcare professional. Therefore, the development of efficacious cognitive training may lead to novel, cost-effective interventions which could be delivered alone or as adjuncts to standard behavioural treatments, as in addiction (Boffo, Pronk, Wiers, & Mannarini, 2015). Furthermore, there have been calls for wider use of cognitive training paradigms to improve executive functioning in individuals with eating disorders, such as anorexia and bulimia (see Juarascio, Manasse, Espel, Kerrigan, & Forman, 2015).

Researchers should remain optimistic for the potential of cognitive training; however we should not ignore the inconsistent results presented here and mounting evidence to suggest the therapeutic potential for these types of interventions in other domains may have been overstated (Christiansen, Schoenmakers, & Field, 2015; Cristea et al., 2015, 2016). In relation to this, many studies synthesised here (and elsewhere) report no changes in the proposed mechanism(s) of action and whilst it is easy to dismiss this as evidence that cognitive training is ineffective, these studies represent an absence of evidence, not evidence of absence (see Clarke, Notebaert, & MacLeod, 2014). In the remainder of this paper we highlight a number of limitations and recommendations for the future.

7. Limitations and recommendations

7.1. Sampling

One issue with both training to improve capacity and training to establish associations is the choice of population under investigation. To establish proof of concept for cognitive interventions, undergraduate students, typically of healthy weight are often recruited. Indeed, our examination of the studies demonstrated that 32/41 (78%) recruited normal weight participants and some did not even state the weight of participants. An over-reliance on homogenous samples is a problem endemic to the field of psychology (Gosling, Vazire, Srivastava, & John, 2004) and is certainly not limited to this field of enquiry. However, as research demonstrates different cognitive performance of overweight/obese individuals compared to controls, not to mention substantial variation within individuals in these populations, it is reasonable to assume that these interventions may have different effects in the populations which they are ultimately intended to benefit. Encouragingly, studies have demonstrated that behavioural effects of some types of cognitive training may be magnified in individuals who are restrained eaters, which suggest that we may see beneficial effects in those motivated to change their weight (Jones et al., 2016; Lawrence, Verbruggen, et al., 2015). Nevertheless, in order to fully assess the potential of cognitive training it will be important

to move away from the practical benefits of testing healthy students and implement these paradigms in their intended populations.

We also note substantial heterogeneity in study methods which makes comparisons difficult, in a number of domains including the number of critical trials, the nature of the comparison or control groups, and the choice and number of outcome measures (Jones et al., 2016). A risk of multiple outcome measures is inflated type 1 error rates, particularly if a primary outcome measure is not identified a priori (Feise, 2002; Tyler, Normand, & Horton, 2011). Similarly, heterogeneity in the motivation of samples often differed across studies, for example, some studies purposely required participants to fast for two hours (Hardman et al., 2013), in other studies participants were satiated (Kemps, Tiggemann, Orr, et al., 2014), whereas other studies incorporated craving manipulations before administration of training (Becker et al., 2015) or did not measure current motivation at all. Combined, these issues make it difficult to interpret and generalize the effects of training. Therefore, we echo calls by other researchers to work towards standardised paradigms and the pre-registration of study designs to allow for a robust synthesis of findings (Chambers, Dienes, McIntosh, Rotshtein, & Willmes, 2015; Franken & van de Wetering, 2015).

Cognitive training literature has also been criticized for adopting a 'one –treatment-fits-all approach', which may limit understanding and progress (Franken & van de Wetering, 2015). The rationale being that whilst deficits in these reflective and impulsive systems are present at a group level, not all individuals exhibit such deficits. For example, what added benefit would AAT bring if individuals did not have strong implicit approach associations that they needed to overcome? Pre-screening individuals for biases and cognitive deficits may increase the therapeutic potential of these paradigms. Similarly, 'not everybody is tempted by the same stimuli' (Hofmann, Friese, & Wiers, 2008), and the need to examine and train associations to stimuli personalized to the individual may be required for improved assessment (Christiansen & Bloor, 2014; Christiansen, Mansfield, Duckworth, Field, & Jones, 2015) and treatment outcomes (Amir, Beard, Burns, & Bomyea, 2009).

Finally, we note that most of these studies had small sample sizes and were most likely underpowered. Poorly powered studies are a pervasive issue across psychology and biomedical sciences as a whole (Button et al., 2013; Vankov, Bowers, & Munafò, 2014). Using pooled effect estimates we previously identified that the average statistical power of cue-ICT studies to be approximately 24% (Munafò et al., 2016). We calculated similar estimates of statistical power (~41%), based on pooled effect sizes for ABM reported in Turton et al. (2016). Based on these estimates, in order to achieve studies with adequate statistical power, laboratory based studies require many more participants (often hundreds) in order to produce meaningful results and as shown in Table 2, this is often not the case. The problem of low statistical power contributes to over-estimates of effect sizes, increased false-negatives (type 2 errors) and low reproducibility (Munafò et al., 2017).

7.2. Control groups and stimuli

A critical limitation with many of the studies described here is the lack of (adequate) control interventions. In open-label studies (Boutelle et al., 2016) and studies with no control manipulation (Brockmeyer et al., 2015) it is impossible to disentangle any beneficial effects of cognitive training from regression to the mean (Morton & Torgerson, 2005) or self-monitoring of behaviour (Michie et al., 2009). When control groups are used they often

implement reversed contingencies, e.g. training inhibitory control may involve inhibiting to 90% of unhealthy food cues, whereas the 'control' group will inhibit to 10%, but crucially make a prompted motor response to the remaining 90%. Importantly, whilst contingency reversal may serve to balance exposure to food cues and the total number of critical responses across groups, it may also inflate the difference between the two groups (Jones et al., 2016). In support of this, Schonberg et al. (2014) demonstrated that making cued-motor responses towards food items increases their value not only immediately, but also for prolonged periods after training (see also Chen et al., 2016). Adams et al. (2017) demonstrated that a control/comparison group that made motor responses to food cues ate more food than cue-ICT groups, however when compared with a control group who made no such motor response but just observed the images (in order to equate cue-exposure across groups) the groups which made motor responses to food ate more. Indeed we note many instances (Table 2) in which reversed contingency control/comparison groups lead to *increased* attentional and approach biases towards food-cues, suggesting effects may be partly driven by increased consumption in the 'attend' or 'approach' groups. The choice of control stimuli also varies across studies, with some studies using neutral images (e.g. stationery) whilst others match stimuli on desirability (e.g. pairing chocolate with strawberries), which further complicates comparisons across studies.

Whilst of the implementation of inadequate control groups in some instances should lead to more cautious interpretations of effects, they may have inadvertently informed associative training paradigms which, rather than attempt to reduce unhealthy food-approach biases, have the goal to *increase* healthy-food approach biases. Indeed, one study trained attention towards healthy food cues (Kakoschke, Kemps, & Tiggemann, 2014) and demonstrated *increased* consumption of healthy foods, compared to a group trained to approach unhealthy food. Therefore, future studies should also examine the effects of training healthy food-approach associations, i.e. cued approach training (Bakkour et al., 2016; Blackburne et al., 2016; Schonberg et al., 2014), in which individuals may be trained to approach salads/vegetables whilst simultaneously avoiding energy dense snack foods (Lawrence, O'Sullivan, et al. (2015); Adams et al., 2017).

7.3. Training in context

Finally, it is possible that a lack of convincing effects outside of the laboratory in some studies may be due to the context-dependency of *associatively-mediated* processes (Rosas, Todd, & Bouton, 2013; Verbruggen et al., 2014). These processes are sensitive to both internal and contextual cues (Jones, Christiansen, Nederkoorn, Houben, & Field, 2013). Indeed, this supports the observation that single and multiple session training conducted in the laboratory have limited effectiveness on behaviour change measured in the real-world (Becker et al., 2015; Forman et al., 2016), and similar issues have reduced enthusiasm for other procedures aimed at extinguishing associations such as cue exposure therapy (Jansen, Schyns, Bongers, & van den Akker, 2016; MacKillop & Lisman, 2008). It appears that most promising effects of cognitive training occur when individuals can attempt it in different contexts, e.g. at home and at work (Lawrence, O'Sullivan, et al. (2015); Veling et al. (2014)), which suggests repeated implementation (Beard, Sawyer, & Hofmann, 2012), via portable devices (Blackburne et al., 2016), and using Ecological Momentary Intervention strategies will be key to promoting long lasting behaviour change (Heron & Smyth, 2010). Attempts at this have demonstrated that participants find the training feasible, acceptable and report high rates of compliance (Boutelle et al., 2016; Lawrence, O'Sullivan, et al., 2015),

which are promising for the future.

8. Conclusion

We synthesised the current evidence for cognitive training as a potential tool for the treatment of overweight and obesity. We identified numerous different types of potential intervention, all of which aim to either increase the *capacity* of reflective processes or alter *associative* approach tendencies towards unhealthy foods. The studies demonstrated promise, in that cognitive training generally influenced outcomes in the laboratory with some evidence of transfer to 'real-world' behaviour. However, the evidence evaluating potential mechanisms was mixed. Future research in this area should be mindful of the limitations we have identified and implement the suggested recommendations to move the field forward and hopefully establish novel and effective psychological interventions that can help people to modify their eating habits and lose weight.

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Contributions

AJ conducted the literature search and wrote the initial draft alongside MF. CH, NL and MF contributed to all subsequent drafts and approved the final manuscript.

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