



This is a repository copy of *Food-related attentional bias and its associations with appetitive motivation and body weight : a systematic review and meta-analysis.*

White Rose Research Online URL for this paper:
<https://eprints.whiterose.ac.uk/166264/>

Version: Accepted Version

Article:

Hardman, C., Jones, A., Burton, S. et al. (6 more authors) (2021) Food-related attentional bias and its associations with appetitive motivation and body weight : a systematic review and meta-analysis. *Appetite*, 157. 104986. ISSN 0195-6663

<https://doi.org/10.1016/j.appet.2020.104986>

Article available under the terms of the CC-BY-NC-ND licence
(<https://creativecommons.org/licenses/by-nc-nd/4.0/>).

Reuse

This article is distributed under the terms of the Creative Commons Attribution-NonCommercial-NoDerivs (CC BY-NC-ND) licence. This licence only allows you to download this work and share it with others as long as you credit the authors, but you can't change the article in any way or use it commercially. More information and the full terms of the licence here: <https://creativecommons.org/licenses/>

Takedown

If you consider content in White Rose Research Online to be in breach of UK law, please notify us by emailing eprints@whiterose.ac.uk including the URL of the record and the reason for the withdrawal request.



eprints@whiterose.ac.uk
<https://eprints.whiterose.ac.uk/>

Food-related attentional bias and its associations with appetitive motivation and body weight: A systematic review and meta-analysis

Charlotte A. Hardman^a, Andrew Jones^a, Sam Burton^a, Jay J. Duckworth^a, Lauren S. McGale^{a, b}, Bethan R. Mead^a, Carl A. Roberts^a, Matt Field^c, Jessica Werthmann^{d, e}

^aDepartment of Psychology, University of Liverpool, UK

^bSchool of Applied Social Sciences, De Montfort University, UK

^cDepartment of Psychology, University of Sheffield, UK

^dDepartment of Clinical Psychology and Psychotherapy, University of Freiburg, Germany

^eInstitute of Psychiatry, Psychology and Neuroscience, Kings College London, United Kingdom

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors. CAH has received research funding from the American Beverage Association and speaker fees from the International Sweeteners Association for work outside of the research reported in this manuscript.

Abstract

Theoretical models suggest that food-related visual attentional bias (AB) may be related to appetitive motivational states and individual differences in body weight; however, findings in this area are equivocal. We conducted a systematic review and series of meta-analyses to determine if there is a positive association between food-related AB and: (1.) body mass index (BMI) (number of effect sizes (k)=110), (2.) hunger (k =98), (3.) subjective craving for food (k =35), and (4.) food intake (k =44). Food-related AB was robustly associated with craving ($r = .134$ (95% CI .061, .208); $p < .001$), food intake ($r = .085$ (95% CI .038, .132); $p < .001$), and hunger ($r = .048$ (95% CI .016, .079); $p = .003$), but these correlations were small. Food-related AB was unrelated to BMI ($r = .008$ (95% CI -.020, .035); $p = .583$) and this result was not moderated by type of food stimuli, method of AB assessment, or the subcomponent of AB that was examined. Furthermore, in a between-groups analysis ($k = 22$) which directly compared participants with overweight/obesity to healthy-weight control groups, there was no evidence for an effect of weight status on food-related AB (Hedge's $g = 0.104$, (95% CI -0.050, 0.258); $p = .186$). Taken together, these findings suggest that food-related AB is sensitive to changes in the motivational value of food, but is unrelated to individual differences in body weight. Our findings question the traditional view of AB as a trait-like index of preoccupation with food and have implications for novel theoretical perspectives on the role of food AB in appetite control and obesity.

Keywords: Attentional bias; appetite; eating; body weight; craving; hunger; motivation; incentive value; executive function

1. Introduction

The number of individuals with overweight and obesity worldwide has continuously increased in most countries since 1980 (Afshin et al., 2017). These rising levels contribute to the increased global incidence of non-communicable disease and have created an unprecedented social and economic burden (Di Angelantonio et al., 2016; Wang, McPherson, Marsh, Gortmaker, & Brown, 2011). Understanding the key drivers of obesity is therefore paramount to developing effective preventive and treatment approaches. The causes of obesity are multi-faceted and impairments within the physiological processes that regulate hunger and satiety are known to be important (MacLean, Blundell, Mennella, & Batterham, 2017). However, it is becoming increasingly apparent that cognitive processes, such as attention and memory, play a critical role in controlling eating and weight-related behaviour (Field et al., 2016; Higgs, 2016; Higgs et al., 2017; Werthmann, Jansen, & Roefs, 2015). One such cognitive process is the tendency to pay attention to stimuli associated with food (e.g., food-related pictures and words).

An attentional bias (AB) to food occurs when food cues selectively capture and hold visual attention (Field et al., 2016). Numerous experimental paradigms are used to assess AB for food cues, most commonly the emotional Stroop task with food words, the visual probe task (or dot probe task), and the visual search task. A brief overview of these paradigms is provided in Table 1. AB can be assessed indirectly in these paradigms based on the measure of response latencies to food cues versus control cues during the task. However, the response latency measures of AB derived from the Stroop and visual probe tasks have poor reliability (Ataya et al., 2012; Rodebaugh et al., 2016). More reliable measures of AB may be obtained by directly monitoring participants' eye movements as they complete the tasks (Christiansen, Mansfield, Duckworth, Field, & Jones, 2015; van Ens, Schmidt, Campbell, Roefs, & Werthmann, 2019). Electroencephalography (EEG) can also be used to record event-related potentials (ERPs) as an index of attentional processing of food-related stimuli during passive viewing or oddball tasks (see Table 1).

Table 1. Overview of experimental paradigms frequently used to assess AB to food cues (see Werthmann, Jansen, and Roefs (2015) for further detail).

Paradigm	Description
Food-Stroop task	Coloured food and non-food words are presented, and participants are required to indicate the colour of the word as quickly as possible, irrespective of the meaning of the word. The Stroop interference score is calculated by obtaining a difference score between the average response latency on food vs. non-food trials. This interference score is thought to reflect biased attention (i.e. an AB for food stimuli is assumed if the response latency is relatively prolonged on food trials relative to non-food trials).
Visual probe task	Two stimuli (a critical stimulus and a non-critical stimulus) are presented side by side on the computer screen for a fixed duration (e.g. 500 ms). Then, both stimuli disappear, and a probe appears in the position of one of the stimuli. Participants are instructed to press a corresponding key on the keyboard to indicate the location of the probe (e.g. left or right side of the screen). It is presumed that participants will react faster to indicate the position of the probe if their attention was already directed to the location (thus on the stimulus) in which the probe appears. Thus, a faster response latency when the probe replaces food stimuli (relative to control stimuli) is thought to reflect an AB to food.
Visual search task	Participants view search matrices depicting several stimuli, with either one presentation of a relevant stimulus (e.g. food) among several irrelevant stimuli (measuring speeded detection) or the presentation of an irrelevant stimulus among several relevant stimuli (measuring increased distraction). Participants have to indicate the 'odd-one-out' stimulus as fast as possible. An attention bias is evidenced by: (a) speeded detection of the relevant among irrelevant stimuli (i.e. early attention) and/or (b) in increased distraction by relevant stimuli when searching for the irrelevant stimulus (i.e. later attention component).
Passive viewing or oddball task with concurrent EEG monitoring	In a passive viewing task, images (e.g. food) are individually presented on a computer screen for several seconds. In an oddball task, participants respond to target stimuli (e.g. food) that occur infrequently and irregularly within a series of control (e.g. non-food) stimuli. During task completion, scalp-mounted electrodes record event-related potentials (ERPs) that are evoked by the stimuli. The amplitude of the P300 and the slow potential components of the ERP in response to food stimuli, relative to control stimuli, is interpreted as a marker of AB to food.

EEG = electroencephalography

In an early study, AB for food words was increased in participants who had fasted for 24 hours compared to participants who were non-fasted (Lavy & van den Hout, 1993). This finding is consistent with evidence indicating that appetitive motivational states are associated with biases in selective attention for motivationally-relevant stimuli (for review see Field, Munafò, & Franken, 2009). Relatedly, it is well-established that aversive motivational

states, such as anxiety, are associated with attentional bias for threat-related cues (Bar-Haim, Lamy, Pergamin, Bakermans-Kranenburg, & van IJzendoorn, 2007). This “motivated attention” is believed to represent automatic attentional capture by stimuli that reflect basic drive states (both appetitive and aversive) that are necessary for an individual to survive (Lang, Bradley, & Cuthbert, 2013). Food-related AB may have been particularly adaptive in our evolutionary past when food sources were scarce and famine was a very real threat (Berthoud, 2004), therefore the ability to rapidly detect and attend to potential food sources is likely to have been highly advantageous (Nijs, Muris, Euser, & Franken, 2010). However, modern westernised environments have been termed “obesogenic” because they are characterized by easy access to energy-dense, palatable foods which are constantly available and extensively marketed (Hall, 2018). There is concern that certain individuals may be particularly responsive to these food cues resulting in increased food cravings, food intake and ultimately weight gain and obesity (Nijs & Franken, 2012). Indeed, in the last decade, the relationship between food AB and hunger, food craving, food intake and weight status in populations with obesity and disordered eating has attracted increasing research interest. A central premise of this research is that food AB could be implicated in the maintenance of problematic eating behaviour and its consequences, including overweight and obesity (Appelhans, French, Pagoto, & Sherwood, 2016; Brooks, Prince, Stahl, Campbell, & Treasure, 2011; Nijs & Franken, 2012; Stojek et al., 2018) .

1.1. Theoretical models of food AB

Numerous theoretical models have been put forward to explain the occurrence of food-related AB. One of the most influential is incentive sensitization theory, which was originally proposed to account for neurobiological adaptations that arise in response to addictive drugs (Robinson & Berridge, 1993, 2008). According to this model, the repeated administration of a drug leads to the development of a sensitized dopaminergic response in brain reward areas (e.g., the nucleus accumbens) and this causes the drug to become highly desired and “wanted”. Through classical conditioning, a cue that is related to the drug also

becomes highly salient, so that it grabs attention (i.e., attentional bias) and guides behaviour towards obtaining the incentive. Recent developments of the theory posit that a similar process occurs in obesity whereby brain reward systems become sensitized to food-related cues which, in turn, leads to increased attention for these cues in the environment (Castellanos et al., 2009; Nijs & Franken, 2012). Moreover, the relationship between attentional bias and substance craving is believed to be mutually excitatory whereby an increase in one produces a corresponding increase in the other (Franken, 2003).

A key prediction from these theoretical accounts is that food AB *causally* contributes to craving and consummatory behaviour. A further prediction is that AB for substance/food cues develops as a consequence of associative learning and once established, it should be an enduring characteristic. Because eating is a universal behaviour and essential for survival, AB for food should be present in almost everybody to some degree (Werthmann, Jansen, & Roefs, 2015). However, because obesity is strongly characterized by overeating (Rosenheck, 2008), food-related AB should be most pronounced in people who have obesity relative to individuals with healthy body weights (Appelhans et al., 2016; Nijs & Franken, 2012). For example, Appelhans et al. (2016) argue that “for obese individuals participating in lifestyle interventions, palatable food may act as a “motivational magnet” that monopolizes attention and triggers lapses in diet adherence” (p.270). These ideas appear intuitive. However, despite intensive research into this subject, empirical evidence for the precise role of AB in craving, food intake and obesity has remained equivocal to date.

1.2. The relationship between food AB and obesity

Narrative reviews of the literature on food-related AB in participants with obesity and healthy body weights have highlighted conflicting findings (Doolan, Breslin, Hanna, & Gallagher, 2015; Nijs & Franken, 2012; Werthmann, Jansen, & Roefs, 2015). For example, Werthmann, Jansen and Roefs (2015) reported that, of 11 published studies, some found that AB was positively associated with obesity and overweight, others found the opposite (smaller AB in participants with overweight/obesity relative to participants of healthy body

weight), and others found no difference. The observed contradictions were attributed to differences between studies in terms of the assessment of AB (direct assessment via eye-tracking vs. indirect assessment using response latencies), the temporal components of AB (early vs. later attention processes), the food stimuli presented (high-calorie vs. low-calorie) and specific characteristics of heterogeneous samples.

Interestingly, Nijs and Franken (2012) found some evidence for an approach-avoid pattern of responding, whereby individuals with overweight/obesity showed enhanced initial attention to food stimuli (particularly high-calorie foods), but reduced maintenance of attention to those stimuli. This was interpreted as reflecting a conflict between an appetitive response (i.e., the desire to eat) which results in strong initial orientation toward food, and an aversive response (i.e., trying to ignore food cues in order to stick to a diet) which results in a subsequent shift in attention away from food. The review by Doolan et al. (2015) similarly suggested that individuals with higher body mass index (BMI) show attentional avoidance of food cues which may represent a cognitive strategy to control food cravings. Werthmann Jansen and Roefs (2015) reviewed the wider literature on populations with obesity, restrained eating, and disordered eating, and found that AB for food could be attributable to both food craving but also concern about over-eating, weight and body shape (Field et al., 2016; Neimeijer, Roefs, & de Jong, 2017). Taken together, these previous reviews support the notion that individuals with overweight and obesity experience motivational conflict when in the presence of food cues.

To our knowledge, there have been only two systematic reviews concerning differences in food AB in individuals with overweight/obesity versus individuals with healthy body weight. Hendrikse et al. (2015) included 19 studies which measured food-related AB using response latency-based paradigms (e.g. visual probe task, food-stroop task), direct measurements of eye movements (i.e., eye-tracking) or neuroimaging methods, and compared participants with overweight (BMI = 25.0–29.9 kg/m²) or obesity (BMI ≥ 30 kg/m²) to a healthy weight control group (BMI = 18.5–24.9 kg/m²). They reported that 15 of the 19 included studies found evidence for enhanced food AB in participants with

overweight/obesity relative to healthy weight participants. However, many of the included studies employed multiple measures of food AB, and often these were differentially associated with overweight and obesity. For example, one of the 15 “positive” studies (Graham, Hoover, Ceballos, & Komogortsev, 2011) found that the overweight group had an AB in initial attentional orientation towards low-calorie foods (not high-calorie foods) using eye-tracking; however there was no difference between the overweight and healthy weight groups on average gaze duration to food images (i.e., a measure of the maintained attention). In another study, there was weak evidence for increased AB in the group with overweight/obesity, relative to the healthy weight group, in the visual probe task with stimuli presented for 100 ms (interpreted as an index of early attentional processing) (Nijs et al., 2010); however there were no differences between the groups on any of the other measures of food AB which were taken in this study (eye-tracking to assess gaze direction and duration, visual probe task with 500 ms stimuli presentation, and recordings of ERPs). Thus, by discounting null or more nuanced results, the results of this previous systematic review are likely to be overly simplistic.

In a more recent systematic review (Hagan, Alasmar, Exum, Chinn, & Forbush, 2020), the effects of different attentional bias paradigms were taken into account by conducting separate meta-analyses per task type (dot probe, emotional stroop, eye-tracking, ERPs). Studies using the dot probe task, eye tracking measures and ERPs were also separately aggregated based on the attentional component measured (e.g., stimulus presentations of ≤ 200 ms and ≥ 500 ms for the dot probe task) as a means of distinguishing between early and late attentional processing. In contrast to Hendrikse et al. (2015), there was little evidence for weight status differences across the different task types and attentional components with the exception of ERP measures, where there was preliminary evidence for an automatic food-related AB in participants with obesity relative to participants of healthy weights. However, this conclusion was based on qualitative assessment of only two studies (meta-analysis was not conducted due to an insufficient number of ERP studies). A further issue with the Hagan et al. (2020) analysis relates to their conclusion that people

with overweight/obesity 'did not differ' from individuals with a healthy weight; it is not statistically correct to conclude the absence of an effect using null hypothesis testing alone (Lakens, McLatchie, Isager, Scheel, & Dienes, 2020).

In summary, previous systematic reviews/meta-analyses have yielded inconsistent findings on the nature of the relationship between food-related AB and obesity. There are also methodological issues with these previous analyses which have hampered understanding and interpretation of the existing evidence base. Furthermore, to our knowledge, there has been little systematic investigation and synthesis of the associations between food-related AB and indices of appetitive motivational state, such as hunger, food cravings, and *ad libitum* food intake, which are key components of existing theoretical accounts of AB.

1.3. *The relationship between food AB and appetitive motivation*

There are many definitions of hunger in the literature, however in appetite research it is commonly operationalised as a "*conscious sensation reflecting a mental urge to eat. Can be traced to changes in physical sensations in parts of the body – stomach, limbs or head. In its strong form may include feelings of light headedness, weakness or emptiness in stomach*" (Blundell et al., 2010) (p.252). In line with this definition, self-report scales (e.g., visual analogue scales) are widely accepted as a standard, sensitive, reliable and valid methodology to quantify current hunger state (Blundell et al., 2010).

Craving for a substance can be defined as "*a subjectively experienced motivational state that fluctuates over time*" (Field et al., 2009, p. 594). In relation to food, cravings are commonly defined as an intense desire which is directed towards a particular food, drink or taste (Hill, 2007). It is the intensity and specificity that distinguishes food cravings from feelings of hunger, and cravings frequently occur when hunger is low (e.g. craving something sweet after a filling savoury meal) (Hill, 2007). In addition, highly-craved foods such as chocolate are often associated with ambivalence due to a conflict between the pleasure of consuming the food and the guilt associated with over-consumption (Rogers &

Smit, 2000). Food cravings are not synonymous with increased food intake, and restriction of a particular food is typically associated with increased craving for that food (Hill, 2007). The subjective experience of food craving is typically measured using single-item visual analogue scales or multi-item craving questionnaires (Cepeda-Benito, Gleaves, Williams, & Erath, 2000).

According to incentive sensitization theory (Robinson & Berridge, 1993, 2008), and associated theoretical accounts applied to food (Appelhans et al., 2016; Nijs & Franken, 2012), food AB is indicative of underlying appetitive motivational processes. Eating is more rewarding when one is hungry (i.e. with hunger being indicated by gastro-intestinal and post-absorptive signals, as well as the time elapsed since the previous meal) (Rogers & Hardman, 2015), therefore it follows that food AB and strength of hunger should be positively correlated. A meta-analysis of AB for positive emotional stimuli versus neutral stimuli included 28 studies with food stimuli (Pool, Brosch, Delplanque, & Sander, 2016). Results revealed a relatively small albeit statistically significant attentional bias for food as compared with neutral stimuli. Importantly, this bias increased when food stimuli were more relevant to the participants' current motivational state (i.e. when they were hungry) relative to when food stimuli were less relevant. This finding supports the idea that food stimuli attract visual attention more than neutral (non-food) stimuli in general, and that current motivational state (hunger) amplifies this relation. However, the Pool et al. meta-analysis did not include information on food intake, weight status of participants or problematic eating behaviour traits and thus cannot inform on the associations between food AB, obesity and consumption. As stated previously, food cravings are intense desires directed towards specific foods, and exposure to palatable food cues can elicit craving and desire towards the cued food, in the absence of energy depletion (Cornell, Rodin, & Weingarten, 1989; Fedoroff, Polivy, & Herman, 1997; Nederkoorn, Smulders, & Jansen, 2000). A meta-analysis from the addiction literature found a small but robust association between drug-related AB and subjective craving (Field et al., 2009), however to the authors' knowledge, no previous

meta-analyses have examined the strength of the AB-craving association in the context of food.

1.4. A novel theoretical perspective

To date, existing reviews on the association between food AB and obesity have provided mixed conclusions. In order to reconcile disparate findings, an alternative theoretical account has been proposed whereby AB is the expression of the momentary motivational evaluation of substance-related stimuli (Field et al., 2016). Specifically, AB for food- and drug-related stimuli arises from momentary changes in evaluations of these stimuli that can be either positive (when the incentive value of the food or drug is high), negative (when individuals have a goal to change their behaviour, and those stimuli are perceived as aversive), or both (when individuals experience motivational conflict, or ambivalence). Importantly, these evaluations of substance-related stimuli and AB are likely to fluctuate substantially within-individuals, and this differs from previous conceptualisations of food AB as a relatively stable trait-like index of preoccupation with food (Appelhans et al., 2016; Berridge, 2009; Nijs & Franken, 2012). The notion that food AB fluctuates within individuals is consistent with novel conceptualisations of more general AB as a “*dynamic process in time*” (Amir, Zvielli, & Bernstein, 2016, p.979); specifically, Zvielli, Bernstein, and Koster (2015) and Amir et al. (2016) provide evidence that AB to threat- and substance-related cues is expressed in fluctuating, phasic bursts towards and/or away from the relevant stimuli from moment-to-moment in time.

If momentary evaluations of food-related cues are key determinants of AB, we would expect subjective motivational states such as hunger and craving to be closely associated with food-related AB. Furthermore, in Field et al.’s (2016) model, both AB and consumption behaviour are outputs of the motivational value of food at that moment in time. Therefore, when AB is measured immediately before food intake and in the same context, there should be a close association between the two (though it is important to note that food intake is not simply a proxy for the incentive value of food and is influenced by an array of other factors

including food availability, dietary restraint and social influences; (Rogers & Hardman, 2015)). Field et al.'s (2016) model further predicts that AB for food cues should only be weakly related to individual differences in body weight and BMI (i.e., consistent with the findings of the Hagan et al. (2020) meta-analysis). This is because within-subject fluctuations in motivational state are postulated to be more influential determinants of AB than more stable between-subject differences. In support of this idea, a recent study found that higher *state* chocolate craving was associated with more positive implicit evaluation of chocolate (assessed using an implicit association task) when current hunger was also high. However *trait* chocolate craving was only indirectly associated with implicit evaluation via its association with *state* craving (Richard, Meule, & Blechert, 2018). Taken together, it would appear that implicit food evaluations are more complex than previously assumed and this may explain why simple between-group comparisons (e.g., individuals with obesity vs. individuals with healthy body weight) do not reveal consistent findings.

Furthermore, as highlighted earlier, individuals with obesity may be particularly likely to experience motivational conflict between the desire to eat palatable foods and the desire to lose weight. Food cues might therefore provoke concerns about eating, and these individuals may attempt to override their food-related AB in order to regulate their emotional and behavioural responses (Field et al., 2016). This motivational conflict may further explain the inconsistent pattern of findings in between-subjects designs when participants with overweight/obesity are compared to participants of healthy body weight.

1.5. The current study

In order to test these novel theoretical predictions and resolve equivocal findings from previous reviews, we conducted a systematic review and meta-analysis in order to quantify the relationships between food-related AB and: (1.) BMI, (2.) hunger, (3.) subjective craving, and (4.) food intake. A key objective was to provide an inclusive, well-powered overview of the strength of the associations between food-related AB, body weight and appetitive motivation across a range of empirical studies which concurrently measured these

variables. This is important as previous systematic reviews/meta-analyses (Hagan et al., 2020; Hendrikse et al., 2015) have been limited to studies which compared a group of participants with overweight/obesity to a healthy weight control group. This has resulted in smaller numbers of studies being included, most notably in sub-group analyses (e.g., meta-analysis was not conducted on the ERP studies in Hagan et al. due to insufficient sample size).

In line with the novel model of AB proposed by Field et al. (2016), we hypothesized that AB for food cues would be more strongly related to the momentary motivational value of food than to individual differences in body weight. On this basis, we predicted that food AB would be closely associated with hunger, subjective craving and food intake, but only weakly associated with BMI.

1.6. Potential moderators of effects

In contrast to previous reviews, we conducted formal sub-group analyses to examine the impact of the following moderators on the associations between food AB and the main variables of interest:

Direct versus indirect measures. AB can be assessed indirectly based on response latencies during experimental tasks or directly by assessing eye movements or ERPs. We hypothesized that the associations between food AB and our variables of interest (BMI, hunger, craving, food intake) would be larger for direct versus indirect measures of attentional bias, as direct measures arguably provide more reliable and valid indices of selective attention (Christiansen et al., 2015; Field et al., 2009).

Early versus later attentional processes. There is an important distinction between the initial orienting of selective attention and the maintenance/disengagement of attention (Corbetta & Shulman, 2002; Treue, 2003; Weierich, Treat, & Hollingworth, 2008). This is particularly relevant in the current context as there is some evidence that individuals with overweight/obesity show enhanced initial attention to food stimuli followed by reduced maintenance of attention to these stimuli (i.e., approach-avoid attentional response) (Nijs &

Franken, 2012; Werthmann, Jansen, & Roefs, 2015; Werthmann et al., 2011). On this basis, we tentatively predicted that the association between food AB and BMI would be larger for measures of early attentional processing relative to measures of late attentional processing. We had no *a priori* hypothesis that the magnitude of the associations between food AB and appetitive motivation (hunger, craving and food intake) would be larger for any particular attentional subcomponent (i.e., early vs. late).

Type of food-related cue presented (high-calorie vs. low-calorie). Several studies have separately assessed AB towards high-calorie food cues (e.g., chocolate, cake, fried foods) and low-calorie food cues (e.g., vegetables, fruit). High-calorie foods, which are typically high in fat and/or sugar, are highly rewarding (Rogers & Brunstrom, 2016) and thus would be expected to capture attention to a greater extent than low-calorie foods. In addition, high-calorie foods such as chocolate, cakes, biscuits, and various salty and savoury snack foods appear high on lists of craved foods (Hetherington & MacDiarmid, 1993; Hill, Weaver, & Blundell, 1991; Rogers & Smit, 2000; Ruddock, Dickson, Field, & Hardman, 2015). On this basis, we tentatively predicted that the associations between food AB and our variables of interest (particularly BMI and craving) would be larger for high-calorie food cues relative to low-calorie food cues.

Sample characteristics of the different studies may also influence results, in particular the weight status of the participants and number of individuals with overweight/obesity in the sample. For example, in studies where there are few individuals with higher BMI there may be insufficient variability in body weight in order to capture weight-related differences in AB to food. In view of this, we separately examined studies which had directly compared a group of participants with overweight/obesity to a healthy weight control group (in line with the previous systematic reviews/meta-analyses by Hagan et al., 2020 and Hendrikse et al., 2015). We tentatively predicted that any differences in food-AB would be most apparent when comparing these more polarized groups of participants.

In summary, our aim was to conduct a systematic review and meta-analysis to determine the strength of the associations between food AB and BMI, hunger, subjective craving and food intake. We further examined whether these associations would be moderated by (1.) the type of assessment method for AB (direct vs. indirect), (2.) the subcomponent of AB (early vs. late), and (3.) the type of food stimuli used in the attention task (high-calorie food stimuli vs. low-calorie food stimuli).

2. Method

2.1. Literature search

Literature searches were guided by Preferred Reporting Items for Systematic Review (PRISMA). The searches were performed during the month of April 2015 and were updated on 26 April 2018 and 11 August 2019 using the databases Pubmed, PsycInfo, Web of Knowledge and Scopus. The following search terms were used: (Attention* bias OR visual probe OR dot probe OR visual search OR Stroop OR eye movements OR event-related potential OR electroencephalic) AND (Food OR eating behav* OR eating OR hunger OR appet* OR obes* OR body mass index OR restrain* OR chocolate).

2.2. Eligibility criteria

To be included in the meta-analysis, studies were required to meet the following criteria: (1.) Peer-reviewed articles written in English; (2.) Tested human participants (studies with both adult and child populations were included); (3.) Used a quantitative approach with either a correlational or experimental study design; (4.) Measured AB to food stimuli in relation to control stimuli by at least one of the following methods: recordings of eye-movements, behavioural response latencies (during tasks including the visual probe, modified stroop, visual search, and flanker tasks) and/or event-related potential (ERP) activity. Consistent with previous meta-analytic investigations (Field et al., 2009), food-related AB indices were defined as the difference between reactivity to food-related cues in

relation to control cues; (5.) Measured body weight as BMI (in kg/m²) and/or current hunger and/or state food craving and/or *ad libitum* food consumption.

We excluded populations with psychiatric disorders and medical conditions unrelated to obesity because this might impact the validity of assessment of AB. As the focus of our analysis was on obesity and appetitive motivation, we also excluded studies of eating disordered populations (e.g., anorexia nervosa, bulimia nervosa). Finally, we excluded studies ($N=12$) which measured food-related AB but also included concurrent measures of body- or shape-related attentional bias because these might prime dietary restriction and hence influence the associations between our variables of interest. This latter criterion generally applied to older studies (i.e., 50% of these were published prior to 1998) which had used non-computerised versions of the emotional stroop task.

2.3. Study selection

The process of inclusion and exclusion of studies is shown in the PRISMA diagram in Figure 1. One author (JW) performed the initial literature searches in April 2015 and April 2018, and two authors (JJD and LSM) performed the final searches in August 2019. In total, the searches yielded 3833 study entries for articles published up to 11 August, 2019. After removing duplicates, the titles and abstracts of the remaining 2316 articles were screened by pairs of authors. Following this process, the full text of 281 remaining articles (including 7 papers which were identified through authors' knowledge) were examined against the eligibility criteria by the pairs of authors. Studies were deemed eligible for inclusion if this was agreed by both authors within the pair. Following this process, the final number of articles eligible for inclusion in each analysis were as follows; 133 articles for the BMI meta-analysis, 98 articles for the hunger meta-analysis, 36 articles for the craving meta-analysis, and 28 articles for the intake meta-analysis.

Insert Figure 1 here

Sample sizes (N s) and correlation coefficients (r) of food-related AB measures with BMI and/or appetitive motivation (hunger, craving, intake) were extracted directly from the

articles where available. In addition, for articles that compared participants with overweight/obesity to a healthy weight control group on food-related AB parameters, the *Ns*, means and standard deviations in the relevant groups were extracted. In the majority of articles, the relevant data were not reported in the desired format because these relationships or comparisons were not the focus of the original article. Therefore, corresponding authors were contacted by email and asked to either calculate the relevant data (correlation coefficients, means, *SDs*, *Ns*) or to provide the raw datafile. Data were obtained from the papers or provided by corresponding authors in this way for 68% (90/133) of eligible articles for the BMI analysis, 72% (71/98) of eligible articles for the hunger analysis, 72% (26/36) of eligible articles for the craving analysis, and 75% (21/28) of eligible articles for the intake analysis (Figure 1). Through this process we were thus able to obtain useable data from the majority of studies which had been identified as eligible for inclusion. We were unable to include data if corresponding authors informed us that they were no longer in possession of the relevant data, or did not respond to the email requests. Corresponding authors were emailed up to a maximum of three times over a three-month period. If no response was received after this period, the corresponding author was deemed non-contactable and it was not possible to include the data from their study in the meta-analysis.

Relevant data were extracted either directly from the articles or as provided from the relevant corresponding author. In cases where included articles were written by authors of the current paper, these authors did not extract data from their own articles in order to reduce bias (e.g., CAH extracted data from (Werthmann, Field, Roefs, Nederkoorn, & Jansen, 2014; Werthmann, Jansen, Vreugdenhil, et al., 2015; Werthmann, Renner, et al., 2014; Werthmann, Roefs, Nederkoorn, & Jansen, 2013; Werthmann et al., 2011; Werthmann, Roefs, Nederkoorn, Mogg, et al., 2013) and JW extracted data from (Hardman, Rogers, Etchells, Houstoun, & Munafo, 2013; Hardman, Scott, Field, & Jones, 2014; Lattimore & Mead, 2015)).

All articles included in the meta-analysis constituted independent samples. The data from Pothos, Tapper and Calitri (2009) and Calitri, Pothos, Tapper, Brunstrom, and Rogers (2010) were not included as these data came from the same sample of participants as reported in a larger study (Pothos, Calitri, Tapper, Brunstrom, & Rogers, 2009); data from this larger study were included in the meta-analyses.

2.4. Primary meta-analysis: selection of AB indices and other variables

The primary attentional bias variables were bias scores which were computed such that a positive score indicated a greater AB towards the target food stimuli. Positive correlation coefficients would thus indicate that greater food AB is associated with higher BMI, hunger, subjective craving and intake. In the article by Bongers et al. (2014), detection bias scores on the visual search task were reported such that negative scores indicated faster detection (i.e. greater AB) of food items than of neutral items. For consistency, we reversed the sign of the correlation coefficients pertaining to these data prior to inclusion in the meta-analyses. Some studies examined AB to a specific type of food (e.g., high-calorie food) in relation to a different food type (e.g., low-calorie food) (Forestell, Lau, Gyurovski, Dickter, & Haque, 2012; Gearhardt, Treat, Hollingworth, & Corbin, 2012; Kakoschke, Kemps, & Tiggemann, 2014). In these cases, a positive bias score indicated a bias towards the specified food-type and a negative bias indicated a bias towards the alternative food stimuli. It was not possible to compute bias scores from the articles by Folkvard, Anschutz, Wiers, and Buijzen (2015) or Hermans et al. (2013) because these studies only measured attention to food cues and did not include comparison stimuli as contrasts. In these cases we used the response data when in the presence of target food-related stimuli, as in previous meta-analysis (Field et al., 2009).

The AB indices included in the primary meta-analysis for each variable were as follows: Direction and duration bias scores for eye-movement data; detection and distraction bias scores for visual search task; response latency data for the visual-probe task; the interference score for the food Stroop. When ERP activity was recorded, we focused on

recordings from the frontal midline electrode (Fz) following the procedure of earlier meta-analyses on the relation of attentional bias to drug or positive stimuli (Field et al., 2009; Littel, Euser, Munafò, & Franken, 2012; Pool et al., 2016). Most ERP studies relied on the Fz recorded P300 measure for food-related attentional bias, which was then entered in the primary data analysis. If several ERP measures were available for the Fz electrode, we included both P300 and the subsequent P300-related late positive potential (LPP) data.

The majority of included articles used multiple methods to assess AB. In these circumstances, we included the most direct measures of AB for the primary meta-analysis. Thus, in the case of articles that included both eye-tracking and response latency data (e.g., concurrent eye-tracking and response latencies were used during the visual-probe task in Castellanos et al. (2009)) we entered the eye-tracking data (both direction bias and duration bias) as primary indices of AB in the primary analysis because eye movements have been recognized as the most direct and reliable measure for visual attention processes (Christiansen et al., 2015; Field et al., 2009). The secondary AB measures (e.g., the response latencies in Castellanos et al., 2009) were used in the stratified analyses to compare direct versus indirect measures of AB (described below). The study by Nijs, Muris, Euser, and Franken (2010) used three assessments of AB (eye-movements, ERP, and response latencies during the visual-probe task). In this case, we entered the eye-tracking data only for the primary analysis and examined the ERP and response latency data in the stratified analyses (see description below). In studies which used multiple stimulus onset asynchrony (SOAs) in the visual probe task (e.g., Tapper, Pothos, & Lawrence, 2010 used 100ms, 500ms and 2000ms SOAs) we entered data averaged across all SOAs in the primary analysis. Data for each individual SOA were included in the stratified analyses.

If multiple measures of hunger and/or state craving were taken within the same experimental procedure, correlations were computed using the measure that was taken closest in time to the measurement of AB. For example, in the study by Lattimore and Mead (2015), we used the correlation between food AB (measured by the visual probe task) and hunger measured immediately after the AB task had been completed. However, if hunger

and/or craving were measured both immediately before and immediately after the AB task (Nijs, Franken, & Muris, 2008, 2010), then we used the correlation between food AB and hunger and/or craving, averaged across pre-test and post-test.

Several studies examined the effects of an experimental manipulation on food-related AB such as a mood (Hepworth, Mogg, Brignell, & Bradley, 2010; Werthmann, Renner, et al., 2014), food availability (Blechert, Feige, Hajcak, & Tuschien-Caffier, 2010; Hardman et al., 2014; Werthmann, Roefs, Nederkoorn, & Jansen, 2013) or *in vivo* food-cue exposure (Lattimore & Mead, 2015). When the experimental manipulation was conducted using a between-subjects study design, consistent with Field, et al., (2009) we used separate data for each group because the experimental manipulations constituted independent groups. When the experimental manipulation was conducted as a within-subjects design, data were averaged across the different conditions and correlations were computed between the averaged values for AB and the other measures.

Seven studies tested the effects of an experimental manipulation of food-related attentional bias (attentional bias modification; ABM) on subsequent food intake while also measuring changes in hunger and/or craving. For the food intake analyses, we used the correlation between AB (assessed either during or immediately after ABM) and *ad libitum* food intake (assessed immediately after ABM) in each experimental group separately (e.g., attend food, avoid food). For craving and hunger, where available, we used correlations between AB and craving/hunger measured post-ABM in each experimental group separately. In cases where post-ABM measures were not taken (e.g. Kemps, Tiggemann, & Hollitt, 2014; Kemps, Tiggemann, Orr, & Grear, 2014), we used correlations between AB and craving/hunger measured at pre-ABM in each experimental group separately. For the BMI analyses, we used correlations between AB measures at pre-ABM and BMI which were collapsed across the different experimental groups. We did this because the groups had not yet undergone the different experimental manipulations and thus constituted one sample. An exception to this was the study by Werthmann, Field, et al. (2014) as this study used eye movements to directly assess AB during the ABM task and therefore pre- and post-ABM

assessments of AB were not needed. For this study, the correlations between AB measured during the ABM task and BMI were used for each group separately.

2.5. Stratified analyses: selection of potential moderators

We considered the following variables in stratified analyses to account for the potential influence of moderating variables on the relationship between food-related AB and BMI, hunger, craving and food intake.

1. The type of assessment method for AB: (a) direct (eye movements, ERPs) versus (b) indirect (response latencies on behavioural tasks) measures (consistent with previous meta-analyses; Field et al., 2009; Pool et al., 2016).

2. The subcomponent of AB: (a) early attentional processes (e.g., initial orienting towards food) versus (b) later attentional processes (e.g., attentional maintenance on or delayed disengagement from food cues). The following were classified as measures of early attentional processing; early measures of eye movements (i.e., direction bias, initial fixation), early ERP components (e.g., P200), visual probe task response latencies with SOAs of 200 ms or less, and visual search detection bias scores (consistent with Field et al., 2009; Hume, Howells, Rauch, Kroff, & Lambert, 2015; Pool et al., 2016). The following were classified as measures of later attentional processing; eye-movement measures of maintained attention (e.g., duration bias, dwell time), late ERP components (e.g., P300 and LPP), response latencies obtained from the food Stroop task, visual search delayed disengagement bias score, and visual probe task response latencies with SOAs greater than 200ms (Field et al., 2009; Phaf & Kan, 2007; Pool et al., 2016).

3. The type of food stimuli used during the attention task: (a) high-calorie foods (i.e., studies that measured AB specifically to high-calorie or high-fat food stimuli in relation to control stimuli) versus (b) low-calorie foods (i.e., studies that measured AB specifically to low-calorie or low-fat food stimuli in relation to non-food control stimuli).

2.6. Statistical approach

Correlation coefficients between indices of AB and BMI, hunger, craving and food intake were included in the meta-analysis. We standardized individual study effect sizes using Fishers Z ($Z = \frac{1}{2} \ln\left(\frac{1+r}{1-r}\right)$) as recommended, and computed the Standard Error ($SE = 1/\sqrt{N - 3}$) (these values can be found in Supplementary Tables 1-4). All analyses were conducted on the standardized correlation coefficients, using restricted maximum likelihood methods as recommended (Langan et al., 2019) using the open source statistics programme, JASP (JASP Team (2020) Version 0.13.1). We opted to use JASP as it permits both standard and Bayesian analyses. For the main analyses on BMI, hunger, craving and intake we averaged correlations from different measures (e.g., direct and indirect; 500 ms SOA and 2000 ms SOA). We supplemented frequentist analyses for the main effects with Bayes Factors using the default priors for the effect size (Cauchy = .707) and heterogeneity (Inverse-Gamma (1, 0.15), but also informed priors (t distribution: location = 0.350; scale = 0.102; df = 3) thought to be plausible for a small-medium effect size (Gronau et al., 2017). In line with Field et al. (2009) we also calculated the r^2 for each correlation coefficient in the main analyses to quantify the amount of variance explained.

For moderator analyses, we split the effect sizes but also corrected for the number of participants (N/number of effect sizes). Hedge's g calculations (which adjust for small sample sizes) for BMI differences in attentional bias were calculated using the 'esc' R package, before analyses. We computed Hedge's g scores for different measures from the same study (e.g., direction and duration biases, P200 and P300) before pooling them for analyses. A positive Hedge's g was indicative of increased attentional bias in the group with overweight /obesity relative to the healthy weight control group. Hedge's g is interpreted as: 0.2 (small), 0.5 (medium), and 0.8 (large). The I^2 statistic was used to assess between-study heterogeneity (over 50% is deemed substantial). Random effects models were used throughout. To test for biases in the data, Eggers test was used to test for symmetry of funnel plots for significant primary analyses.

Subgroup analyses were conducted in JASP by comparing the effect sizes across different groups using the chi-squared statistic for the following comparisons: Direct vs. indirect measures of attention; Early vs. late attentional processing; High-calorie vs. low-calorie food cues.

3. Results

3.1. BMI analysis

The included studies and associated r values for the association between AB and BMI in the main analysis are shown in Supplementary Table 1 (number of effect sizes (k) in main analysis = 110 drawn from 90 articles). The data pertaining to all subgroup analyses are provided in separate tabs in Supplementary Table 1.

There was no significant overall relationship between BMI and AB, ($r = .008$, 95% CI $-.020, .035$); $Z = 0.549$, $p = .583$, $I^2 = 11.98\%$). Attentional bias predicted $< 1\%$ variance in BMI ($r^2 < .001$). Bayesian meta-analyses provided very strong support for the Null Hypotheses using default priors ($BF^{01} = 53.93$), and informed priors ($BF^{01} = 152.06$).

A separate analysis was conducted on studies which directly compared AB in a group of participants with overweight/obesity to a healthy weight control group ($k = 22$, drawn from 20 articles). This analysis revealed an overall Hedge's g of 0.104, (95% CI $-0.050, 0.258$); $Z = 1.323$, $p = .186$, $I^2 = 24.15\%$) (see Figure 2 and Supplementary Table 1). Bayesian meta-analysis provided moderate evidence for the null hypothesis using default priors ($BF^{01} = 4.43$) and weak evidence using informed priors ($BF^{01} = 2.07$). Across the included articles¹, the overall mean (\pm SD) BMI in the groups with overweight/obesity was 33.73 (± 4.05 ; minimum mean BMI = 28.03, maximum mean BMI = 38.8) kg/m². The overall mean BMI in the healthy weight control groups was 21.82 (± 0.64 ; minimum mean BMI = 20.63, maximum mean BMI = 22.68) kg/m².

Insert Figure 2 here

¹ Only for studies in adults where BMI descriptive data could be extracted from the article (14 articles in total).

Direct vs indirect. There was no relationship between BMI and direct ($r = -.043$, (95% CI $-.098$, $.012$); $Z = -1.52$, $p = .129$, $I^2 = 0$) or indirect ($r = .016$, (95% CI $-.015$, $.048$); $Z = 1.01$, $p = .314$, $I^2 = 9.17$) measures of AB. Furthermore, the test for subgroup differences was not significant ($Q(1) = 3.56$, $p = .059$).

Early vs Late. There was no relationship between BMI and early ($r = -.013$, (95% CI $-.078$, $.053$); $Z = -0.375$, $p = .707$, $I^2 = 0$) or late attentional bias ($r = .007$ (95% CI $-.027$, $.040$); $Z = 0.404$, $p = .686$, $I^2 = 10.13$). Furthermore, the test for subgroup differences was not significant ($Q(1) = 0.339$, $p = .561$).

High-calorie vs Low-calorie. There was no relationship between BMI and AB for high-calorie food stimuli ($r = .005$ (95% CI $-.038$, $.048$); $Z = 0.227$, $p = .820$, $I^2 = 0$) or low-calorie food stimuli ($r = -.008$ (95% CI $-.082$, $.066$); $Z = -0.217$, $p = .828$, $I^2 = 0$). Furthermore, the test for subgroup differences was not significant ($Q(1) = 0.091$, $p = .763$).

3.2. Hunger

The included studies and associated r values for the association between AB and hunger are shown in Supplementary Table 2. The data pertaining to all subgroup analyses are provided in separate tabs in Supplementary Table 2.

Overall, there was evidence for a relationship between hunger and AB ($k = 98$, $r = .048$ (95% CI $.016$, $.079$); $Z = 2.941$, $p = .003$, $I^2 = 17.53$). Attentional bias predicted $< 1\%$ of variance in hunger ($r^2 = .002$). Eggers test was significant (intercept = 1.99 , $p = .047$), suggesting asymmetry. Bayes factors suggest this evidence for the alternative hypothesis was weak using default priors ($BF^{10} = 1.27$) and informative priors ($BF^{10} = 0.679$).

Direct vs. Indirect. There was a significant relationship between hunger and direct measures of AB ($r = .089$ (95% CI $.029$, $.149$); $Z = 2.920$, $p = .003$, $I^2 = 0.00$), but not between hunger and indirect measures of AB ($r = .030$ (95% CI $-.009$, $.069$); $Z = 1.516$, $p = .130$, $I^2 = 23.10$). However, there was no significant subgroup difference ($Q(1) = 2.786$, $p = .095$).

Early vs. Late. There was no significant relationship between hunger and early attentional processing ($r = .074$ (95% CI $-.011, .159$); $Z = 1.716$, $p = .086$, $I^2 = 0$) or between hunger and late attentional processing ($r = .024$ (95% CI $-.008, .056$); $Z = 1.460$, $p = .144$, $I^2 = 0$)². The test for subgroup differences was not statistically significant ($Q(1) = 1.18$, $p = .277$)².

High-calorie vs. low-calorie food stimuli. There was no relationship between hunger and AB for high-calorie food stimuli ($r = .019$ (95% CI $-.025, .063$); $Z = 0.833$, $p = .405$, $I^2 = 0$) or low-calorie food stimuli ($r = .037$ (95% CI $-.056, .130$); $Z = 0.785$, $p = .433$, $I^2 = 0$). Furthermore, the test for subgroup differences was not significant ($Q(1) = 0.124$, $p = .725$).

3.3. Craving

The included studies and associated r values for the association between AB and craving are shown in Supplementary Table 3. The data pertaining to all subgroup analyses are provided in separate tabs in Supplementary Table 3.

Overall, there was a significant relationship between AB and craving ($k = 35$, $r = .134$ (95% CI $.061, .208$); $Z = 3.570$, $p < .001$, $I^2 = 39.80$). Attentional bias predicted ~1.7% of variance in craving ($r^2 = .017$). Eggers test was significant (intercept = 2.16 $p = .031$) suggesting that the funnel plot was asymmetrical. Bayes factors were strongly supportive of the alternative hypothesis using default priors ($BF^{10} = 18.16$) and informed priors ($BF^{10} = 26.37$).

Direct vs. Indirect. There were associations between both direct ($r = .134$ (95% CI $.042, .227$); $Z = 2.848$, $p = .004$, $I^2 = 0.16$) and indirect ($r = 0.112$ (95% CI $.016, .208$); $Z = 3.295$, $p = .022$, $I^2 = 34.63$) measures of AB and craving. The test for subgroup differences was not significant ($Q(1) = 0.210$, $p = .647$).

Early vs. Late. There was no significant association between early AB and craving ($r = .107$ (95% CI $-.063, .277$); $Z = 1.229$, $p = .219$, $I^2 = 0.0$), but a significant association

² Maximum likelihood estimation did not converge for this meta-analysis, therefore we used DerSimonian-Liard method.

between late AB and craving ($r = .121$ (95% CI = .050, .192); $Z = 3.333$, $p < .001$, $I^2 = 16.8$). However, the test for subgroup differences was not significant ($Q(1) = 0.021$, $p = .884$).

High-calorie vs. low-calorie food stimuli. There was a significant relationship between craving and AB for high-calorie ($r = .148$ (95% CI .061, .236); $Z = 3.309$, $p < .001$, $I^2 = 18.8$) but not low-calorie food cues ($r = .048$ (95% CI -.450, .546); $Z = 0.189$, $p = .850$, $I^2 = 0.00$). However, the test for subgroup differences was not significant ($Q(1) = 0.145$, $p = .703$).

3.4. Food intake

The included studies and associated r values for the association between AB and food intake are shown in Supplementary Table 4. The data pertaining to all subgroup analyses are provided in separate tabs in Supplementary Table 4.

Overall, there was a significant relationship between AB and food intake ($k = 44$, $r = .085$ (95% CI .038, .132); $Z = 3.53$, $p < .001$, $I^2 = 5.0$). Attentional bias predicted < 1% of variance in food-intake ($r^2 = .007$). Eggers test was not significant (intercept = 0.71, $p = .476$). Bayes factors were moderately supportive of the alternative hypothesis using default ($BF^{10} = 4.29$) and informed priors ($BF^{10} = 3.42$).

Direct vs. Indirect. There was a significant relationship between indirect ($r = .100$ (95% CI .043, .157); $Z = 3.420$, $p < .001$, $I^2 = 1.97$) but not direct ($r = .022$ (95% CI -.064, .107); $Z = 495$, $p = .620$, $I^2 = 0.00$) AB measures and intake. There was no significant subgroup difference ($Q(1) = 2.32$, $p = .127$).

Early vs. Late. There was a significant relationship between intake and late ($r = .073$ (95% CI .019, .127); $Z = 2.653$, $p = .008$, $I^2 = 0.00$), but not early ($r = .085$ (95% CI -.111, .281); $Z = 0.846$, $p = .397$, $I^2 = 19.9$) attentional processing. However, there was no significant subgroup difference ($Q(1) = 0.050$, $p = .824$).

No studies examined the association between AB specifically to low-calorie foods and food intake. Therefore, it was not possible to carry out stratified analyses comparing high-calorie versus low-calorie food stimuli in relation to food intake.

4. Discussion

According to many theoretical accounts, food AB should be most pronounced in people who have obesity relative to individuals of healthy body weight. It should also be (causally) associated with craving and consummatory behaviour. However, empirical evidence for the precise role of AB in obesity and appetitive motivation has remained equivocal. The current study conducted a systematic review and a series of meta-analyses to determine if there is a relationship between food-related AB and: (1.) body mass index (BMI), (2.) hunger, (3.) subjective craving, and (4.) food intake. Results indicated that food-related AB was robustly associated with subjective craving and proximal food intake and weakly with current levels of hunger. However, there was no meaningful association between food-related AB and BMI.

The positive associations found between food-related AB and craving, hunger and food intake are consistent with our hypothesis and the notion that AB to food cues reflects underlying appetitive motivation, as predicted by incentive sensitization theory (Robinson & Berridge, 1993, 2008). The more recent theoretical perspective by Field et al. (2016) similarly predicts that food AB will be increased when the incentive value of food is high and food stimuli are thus evaluated positively (note that Field et al. postulate that AB can also arise due to negative evaluations and/or motivational conflict towards food stimuli; the magnitude of the observed food AB thus reflects the *strength* of the evaluation rather than its valence). Critically, in Field et al.'s model, these evaluations towards food stimuli and food AB are thought to be transient and to fluctuate substantially within individuals (see also Amir et al., 2016; Zvielli et al., 2015). On this basis, we would expect food-related AB to be closely associated with state measures of motivation (craving, hunger, proximal food intake) which are taken at the same moment in time. In line with this, there is also evidence that performance on other cognitive tasks fluctuates over time within-individuals. Powell, McMinn, and Allan (2017) used ecological momentary assessment (EMA) over 7 consecutive days to quantify within-subjects variability in inhibitory control (using hourly Go/No-Go tests) in relation to subsequent snacking behaviour. Results showed that lower momentary inhibitory

control performance predicted higher subsequent snack consumption at the within-subject level; however, importantly snacking was not explained by between-subject trait-level differences in inhibitory control. With regard to approach biases, it has been shown that food-related approach bias was associated with participants' momentary desire to eat the specific food items, but not with overall state or trait food cravings (Kahveci, Meule, Lender, & Blechert, 2020).

The lack of association between AB and BMI is also consistent with Field et al. (2016), who postulated that within-subject differences in motivational state and momentary evaluations of food-related cues may be more influential determinants of AB than more stable between-subject characteristics, such as individual differences in body weight (see also Richard et al., 2018). In this way, the effects of the former may mask the effects of the latter thus explaining the null association between food AB and BMI in the current results. This is in contrast to incentive sensitization theory which holds that, once food-AB is established, it should be an enduring characteristic of individuals who habitually overeat (i.e., individuals with obesity). However, empirical support for this proposition is conflicting, with some studies showing that AB is positively associated with obesity, others showing the opposite (smaller AB in participants with obesity) and other studies finding no differences, or that differences that are moderated by other characteristics (e.g., hunger state) (Doolan et al., 2015; Werthmann, Jansen, & Roefs, 2015). Our findings indicate that, across a broad range of empirical studies, the overall association between food-related AB and BMI is negligible and furthermore this result was not moderated by type of food stimuli, method of AB assessment, or the subcomponent of AB that was examined. In the addiction literature, meta-analyses have confirmed a more pronounced AB to substance-related cues in habitual users of these substances relative to non-users (Cox, Fadardi, & Pothos, 2006; Littel et al., 2012; O'Neill, Bachi, & Bhattacharyya, 2020); however, the greater AB in drug users could reflect higher familiarity and/or greater appetitive-motivational state. Importantly, within user groups, there is no consistent relationship between greater frequency/quantity of substance

use and the magnitude of AB, which is contrary to predictions of incentive-sensitization theory (Field et al., 2016).

Our findings for body weight conflict with the earlier systematic review by Hendrikse et al. (2015) but are broadly consistent with the more recent meta-analysis (Hagan et al., 2020) which also found no evidence for differences by weight status on a range of food-related AB assessments. The only difference is that, for the analysis of ERP measurements, Hagan et al. found weak evidence for a bias on automatic attention in individuals with obesity. However, as noted previously this was based on findings from only two studies and a meta-analysis was not conducted due to inadequate sample size. Furthermore, whilst the authors of this meta-analysis claim no difference between individuals with healthy weight versus individuals with obesity, it is not statistically correct to conclude the absence of an effect using null hypothesis testing alone (Lakens et al., 2020). Our analysis addresses this issue and our Bayes factors did provide weak support for the null hypothesis in this case.

Furthermore, both Hendrikse et al. (2015) and Hagan et al. (2020) only included studies which explicitly compared AB in participants with overweight/obesity to AB in healthy weight control groups. In contrast, in our study we treated BMI as a continuous variable and examined the association between BMI and food-related AB across a range of empirical studies which had concurrently measured both of these variables. An advantage of this approach is that we were able to include a larger number of studies (110 effect sizes (k) drawn from 90 studies) in our analyses compared to the 19 articles reviewed by both Hendrikse et al. (2015) and Hagan et al. (2020). Several of the studies we included were designed to address unrelated research questions (i.e., both food AB and BMI were measured, however their association was not the main focus of the study). This is a potential issue as it may have led to recruitment of participants with a narrow range of BMIs and therefore there may have been insufficient variability to capture associations with food AB. To account for this, we also ran a between-groups analysis to directly compare food AB in studies which had a group of participants with overweight/obesity and a healthy weight control group (with clear differences in BMI between these two groups). The results of this

analysis (on 22 effect sizes; Figure 2) similarly found no evidence for a difference between groups with overweight/obesity and healthy weight on food-related AB, which is consistent with the findings of the recent meta-analysis by Hagan et al. (2020).

With regard to the different indices of appetitive motivation, our results indicate that subjective craving was most strongly associated with food-related AB ($r = .134$), and the magnitude of this association is similar to that found between craving and AB to drug-related cues ($r = .190$) (Field et al., 2009). The association between current hunger and AB was statistically significant, but considerably smaller ($r = .048$). In many of the included studies, participants were fasted for a few hours or overnight, and more extensive periods of food restriction may be needed to promote larger differences in AB. Conditions of being fasted also require more rigorous control (e.g., by having participants remain in the laboratory throughout the fasting period) which is not always feasible or practical. It may also be important to consider the correspondence between recently eaten foods and the food stimuli that are included in the assessment of AB. Sensory-specific satiety (SSS) refers to the decline in the reward value of recently-eaten foods, relative to foods which have not been recently eaten (Rolls, Rolls, Rowe, & Sweeney, 1981). Notably, di Pellegrino, Magarelli and Mengarelli (2011) showed that food AB is sensitive to this effect. In their study, AB for a food that was eaten to satiety decreased markedly from pre- to post-satiety, along with the subjective pleasantness of that food; however, subjective pleasantness and AB for an alternative food, which was not eaten, did not show any such decrease (see also Davidson, Giesbrecht, Thomas, and Kirkham (2018)). These findings suggest that satiety does not have a straightforward effect of reducing AB, and importantly AB of certain (i.e., uneaten) foods may be maintained despite recent eating. In addition, food cravings frequently occur in the absence of hunger (Hill, 2007), and Fedoroff, Polivy, and Herman (2003) showed that elevated cravings following food cue exposure are highly food-specific (i.e. desire to eat, liking and craving for pizza were significantly higher after exposure to a pizza cue relative to a cookie cue or no cue) (see also Kemps et al., 2016 for comparable findings for a low-calorie food). On this basis, food-specific cravings would be expected to be more closely

related to AB for that same food than subjective levels of hunger per se, as the results of our meta-analysis indicate.

We also found that food-related AB was positively associated with food intake. In the included studies, food intake was measured close in time to the measure of AB and in the same context most commonly using the “bogus” taste test methodology (i.e., where participants are provided with large amounts of food items to evaluate on various taste dimensions while their consumption is unobtrusively measured) (Robinson et al., 2017). In the current analyses we examined cross-sectional associations between AB and food intake, and thus our findings are unable to speak to any causal relationship between these variables, including a causal effect of increased AB on overeating that is predicted by some theoretical models (e.g., Appelhans et al., 2016). Indeed, AB and intake may co-vary because they are both outputs of the incentive value of food at that moment in time (Field et al., 2016). The causal role of AB in increasing food craving and intake can be examined by experimentally manipulating food AB (attentional bias modification; ABM). ABM studies typically use a modified visual-probe task in which the location of the visual probe is systematically varied so that participants are trained to either attend towards food stimuli or away from food stimuli before subjective motivational states and behaviour are assessed. Notably, a meta-analysis on a small number of studies reported a medium effect of ABM (training away from unhealthy food) on reducing unhealthy food consumption (Turton, Bruidegom, Cardi, Hirsch, & Treasure, 2016). Although these results appear promising, the small evidence base and lack of control groups in most of the studies mean that firm conclusions around the causal role of AB in food intake, and potential for ABM to be used as an intervention strategy, cannot yet be drawn.

We also examined whether the strength of the overall associations in our meta-analyses would be moderated by the assessment method for AB (direct vs. indirect), the subcomponent of AB examined (early vs. late attention), and type of food stimuli used during the attention task (high-calorie foods vs. low-calorie foods). The results revealed some interesting differences. For example, for craving and food intake, there was some evidence

for associations with late AB but not early AB. Consistent with the elaborated intrusion theory of desire (Kavanagh, Andrade, & May, 2005; May, Kavanagh, & Andrade, 2015), encountering salient food cues may trigger “elaborated” thoughts and give rise to craving which, in turn, influences top-down attentional focus on craving-relevant information. Craving may therefore be associated with late attentional processing (i.e., delayed disengagement from food cues) because it is a form of rumination whereby food/eating-related information is rehearsed in working memory (WM) which drives attention towards food cues (see Higgs, Rutters, Thomas, Naish, & Humphreys, 2012). As a consequence, it may become more difficult to control the attention directed to craving-related cues due to their salience and maintenance in WM. There was also a significant relationship between craving and AB to high-calorie, but not low-calorie, food cues which likely reflects the greater desirability of high-calorie foods (Rogers & Brunstrom, 2016). However, a relatively small number of the included studies measured AB specifically to low-calorie foods (relative to non-food control stimuli). Furthermore, none of the formal subgroup analyses reached statistical significance, and so these findings must be interpreted with caution.

Relative to individuals of healthy weight, people with overweight and obesity may experience greater motivational conflict between the desire to eat palatable foods and the desire to adhere to a diet (Nijs & Franken, 2012; Werthmann, Jansen, & Roefs, 2015). Food-related AB may therefore arise when people experience motivational conflict, and, in these circumstances, they may attempt to override or control their AB by engaging in attentional avoidance (Field et al., 2016). In support of this idea, previous studies have shown an approach-avoid pattern of AB in individuals with overweight/obesity, whereby attention is initially directed towards food cues, however subsequent maintained attention on these cues is reduced, relative to healthy weight individuals (Nijs & Franken, 2012; Werthmann, Jansen, & Roefs, 2015; Werthmann et al., 2011). We did not find support for this phenomenon in the current meta-analysis; for both early and late attentional processing there was no significant association between AB and BMI (see also Hagan et al., 2020 for comparable findings). These null findings could be attributable to methodological aspects of the included studies –

for example, traditional measures of AB (i.e., response latencies derived from the visual probe and Stroop tasks) are not able to capture attentional processes linked to motivational conflict. Indeed, the Stroop effect (i.e., the slow-down in colour-naming when reading a food word versus when reading a neutral word) could be caused either by increased attention to the semantic meaning of the stimulus word, or by avoidance of processing the stimulus word (Yiend, 2010). It is not always possible to distinguish between initial orienting and maintained attention, and the use of shorter versus longer SOAs in tasks such as the visual probe only provide an indirect indicator of the underlying attentional processes (Pool et al., 2016). Existing tasks often do not distinguish bottom-up (reward-driven) and top-down (pre-occupation, elaboration in working memory) attentional processes, which may be required in order to detect differences by weight status (e.g. see Kaisari et al., 2019).

Field et al. (2016) also proposed that motivational fluctuations over time in relation to food cues (appetitive/aversive) may be more pronounced in individuals with obesity relative to individuals of healthy weight. None of the studies included in the current analysis used an attention assessment method that could adequately capture these rapid changes in food AB. This is an evolving field of enquiry and, in relation to the visual-probe task, new indices (trial-level bias scores) have recently been proposed to enable measurement of the dynamic expression of AB over time (Amir et al., 2016; Zvielli et al., 2015). Importantly these novel bias indices have superior reliability in comparison to traditionally-used bias scores in which AB is measured as a stable, trait-like process (Rodebaugh et al., 2016) (though see Kruijt, Field, & Fox, 2016 for a critique of this approach). Using novel methods to measure fluctuations in AB both towards and away from food cues in individuals with obesity (relative to healthy weight individuals) is an exciting area for future research. Ecological momentary assessment (EMA) has been used to capture naturalistic within-subject changes in cognition in relation to snacking (Powell et al., 2017), and a recent EMA study found that higher momentary food-related AB (using an ambulatory dot-probe task) was associated with binge eating (Smith et al., 2020).

Trait dietary restraint is also associated with motivational conflict and, while restraint *per se* is not consistently associated with food AB (Werthmann, Jansen, & Roefs, 2015), it may moderate the association between AB and BMI. Notably, Papies et al. (2008) showed that restrained eaters, but not unrestrained eaters, displayed an AB for palatable food items when hedonic eating goals were primed (via pre-exposure to palatable food cues) but not when dieting goals were primed (see also Werthmann, Jansen, & Roefs, 2016). These findings support other research indicating that momentary goal salience is a key determinant of AB (Field et al., 2016). On this basis, the strength of the associations between AB, BMI and dietary restraint may depend on the extent to which particular goals are activated at that moment in time (i.e., motivational conflict may be more likely to occur if dieting goals are activated) and this prospect merits scrutiny in future studies. Focusing on specific eating behaviour traits, rather than BMI, may also be a more profitable line of enquiry. For example, a recent systematic review (Stojek et al., 2018) found evidence for AB towards food in individuals who engage in binge eating.

A limitation of this evidence base, and that of attentional bias more generally, is that it is often measured by tasks with poor psychometric properties (Jones, Christiansen, & Field, 2018) (though see also van Ens et al., 2019). Reliability places an upper bound on the observed associations between variables (Matheson, 2019), and can also reduce statistical power (Parsons, Kruijt, & Fox, 2018). As such, it is possible that the associations reported are confounded by measurement error, and future research should report reliabilities. Notably, a recent study indicated several ways to improve reliability of food-related AB scores, such as using longer stimulus presentation times (≥ 3000 ms) and use of eye-tracking measurements (van Ens et al., 2019), which merit consideration in future studies. Our analyses also demonstrated some evidence of publication bias, which might suggest increased presence of 'positive' results in the literature (Mlinarić, Horvat, & Šupak Smolčić, 2017). This 'publication bias' might lead to overestimates of the associations obtained from meta-analyses (Thornton & Lee, 2000). Finally, there was considerable variability across the included studies in the extent to which target food-related images were matched to control

images on characteristics such as valence, arousal and physical properties. We concur with Hagan et al. (2020) that future AB researchers should make use of images from standardized open access databases, such as the Food Cast research image database (FRIDa) (Feroni, Pergola, Argiris, & Rumiati, 2013) and *food-pics* (Blechert, Meule, Busch, & Ohla, 2014). Notably, *Food-Pics_Extended* (Blechert, Lender, Polk, Busch, & Ohla, 2019) comes with 315 non-food control images (including animals, flowers, tools, household and office items) which can be matched to the food images on ratings of valence, arousal and other image characteristics.

In conclusion, in this extensive synthesis of studies, we have shown that food AB is associated with subjective craving for food, proximal food intake, and to a lesser extent, with subjective hunger. However, food AB was not associated with individual differences in BMI. These findings are important to understanding the processes underpinning food-related AB and suggest that theoretical perspectives on the role of food AB in obesity may need to be refined. Specifically, our findings question the traditional view of AB as a trait-like index of preoccupation with food and are instead consistent with the notion that food AB is sensitive to the motivational value of food at that moment in time. However the associations between food AB and indices of appetitive motivation were small (food AB explained <2% of variance in craving, hunger and food intake) which is important to take into account particularly when considering the practical applications of AB research for behaviour change interventions. Future research using new assessment methods that are able to capture rapid within-subject fluctuations in attention to and away from food cues is now needed.

Acknowledgements

We thank all authors who provided data in a format that enabled their inclusion in the meta-analyses we report.

Data Availability

The corresponding data files for the analyses can be found on Open Science Framework, <https://osf.io/ks7x5/>

References

NB. Reference list for articles included in the meta-analyses can be found in the Supplementary Materials.

- Afshin, A., Forouzanfar, M. H., Reitsma, M. B., Sur, P. J., Estep, K., Lee, A., & Marczak, L. (2017). Health Effects of Overweight and Obesity in 195 Countries over 25 Years. *New England Journal of Medicine*, *377*(1), 13-27. doi:10.1056/NEJMoa1614362
- Amir, I., Zvielli, A., & Bernstein, A. (2016). (De) coupling of our eyes and our mind's eye: A dynamic process perspective on attentional bias. *Emotion*, *16*(7), 978.
- Appelhans, B. M., French, S. A., Pagoto, S. L., & Sherwood, N. E. (2016). Managing temptation in obesity treatment: A neurobehavioral model of intervention strategies. *Appetite*, *96*, 268-279.
- Ataya, A. F., Adams, S., Mullings, E., Cooper, R. M., Attwood, A. S., & Munafò, M. R. (2012). Internal reliability of measures of substance-related cognitive bias. *Drug & Alcohol Dependence*, *121*(1), 148-151. doi:10.1016/j.drugalcdep.2011.08.023
- Bar-Haim, Y., Lamy, D., Pergamin, L., Bakermans-Kranenburg, M. J., & van IJzendoorn, M. H. (2007). Threat-related attentional bias in anxious and nonanxious individuals: a meta-analytic study. *Psychol Bull*, *133*(1), 1-24. doi:10.1037/0033-2909.133.1.1
- Berridge, K. C. (2009). 'Liking' and 'wanting' food rewards: Brain substrates and roles in eating disorders. *Physiology & Behavior*, *97*(5), 537-550.
- Berthoud, H. R. (2004). Mind versus metabolism in the control of food intake and energy balance. *Physiol Behav*, *81*(5), 781-793. doi:10.1016/j.physbeh.2004.04.034
- Blechert, J., Feige, B., Hajcak, G., & Tuschen-Caffier, B. (2010). To eat or not to eat? Availability of food modulates the electrocortical response to food pictures in restrained eaters. *Appetite*, *54*(2), 262-268.
- Blechert, J., Lender, A., Polk, S., Busch, N. A., & Ohla, K. (2019). Food-Pics_Extended—An Image Database for Experimental Research on Eating and Appetite: Additional Images, Normative Ratings and an Updated Review. *Frontiers in Psychology*, *10*(307). doi:10.3389/fpsyg.2019.00307
- Blechert, J., Meule, A., Busch, N. A., & Ohla, K. (2014). Food-pics: an image database for experimental research on eating and appetite. *Frontiers in Psychology*, *5*(617). doi:10.3389/fpsyg.2014.00617
- Blundell, J., de Graaf, C., Hulshof, T., Jebb, S., Livingstone, B., Lluch, A., . . . Westerterp, M. (2010). Appetite control: methodological aspects of the evaluation of foods. *Obes Rev*, *11*(3), 251-270. doi:10.1111/j.1467-789X.2010.00714.x
- Bongers, P., van de Giessen, E., Roefs, A., Nederkoorn, C., Booij, J., van den Brink, W., & Jansen, A. (2014). Being Impulsive and Obese Increases Susceptibility to Speeded Detection of High-Calorie Foods. *Health Psychol*. doi:10.1037/hea0000167
- Brooks, S., Prince, A., Stahl, D., Campbell, I. C., & Treasure, J. (2011). A systematic review and meta-analysis of cognitive bias to food stimuli in people with disordered eating behaviour. *Clinical psychology review*, *31*(1), 37-51.
- Calitri, R., Pothos, E. M., Tapper, K., Brunstrom, J. M., & Rogers, P. J. (2010). Cognitive biases to healthy and unhealthy food words predict change in BMI. *Obesity*, *18*(12), 2282-2287.
- Castellanos, E. H., Charboneau, E., Dietrich, M. S., Park, S., Bradley, B. P., Mogg, K., & Cowan, R. L. (2009). Obese adults have visual attention bias for food cue images: evidence for altered reward system function. *International Journal of Obesity*, *33*(9), 1063-1073.
- Cepeda-Benito, A., Gleaves, D. H., Williams, T. L., & Erath, S. A. (2000). The development and validation of the state and trait food-cravings questionnaires. *Behavior Therapy*, *31*(1), 151-173. doi:[https://doi.org/10.1016/S0005-7894\(00\)80009-X](https://doi.org/10.1016/S0005-7894(00)80009-X)

- Christiansen, P., Mansfield, R., Duckworth, J., Field, M., & Jones, A. (2015). Internal reliability of the alcohol-related visual probe task is increased by utilising personalised stimuli and eye-tracking. *Drug Alcohol Depend*, *155*, 170-174. doi:10.1016/j.drugalcdep.2015.07.672
- Corbetta, M., & Shulman, G. L. (2002). Control of goal-directed and stimulus-driven attention in the brain. *Nature Reviews Neuroscience*, *3*(3), 201.
- Cornell, C. E., Rodin, J., & Weingarten, H. (1989). Stimulus-induced eating when satiated. *Physiology & Behavior*, *45*(4), 695-704. doi:[https://doi.org/10.1016/0031-9384\(89\)90281-3](https://doi.org/10.1016/0031-9384(89)90281-3)
- Cox, W. M., Fadardi, J. S., & Pothos, E. M. (2006). The Addiction-Stroop test: Theoretical considerations and procedural recommendations. *Psychological Bulletin*, *132*(3), 443-476. doi:10.1037/0033-2909.132.3.443
- Davidson, G. R., Giesbrecht, T., Thomas, A. M., & Kirkham, T. C. (2018). Pre- and postprandial variation in implicit attention to food images reflects appetite and sensory-specific satiety. *Appetite*, *125*, 24-31. doi:10.1016/j.appet.2018.01.028
- Di Angelantonio, E., Bhupathiraju, S. N., Wormser, D., Gao, P., Kaptoge, S., de Gonzalez, A. B., . . . Hu, F. B. (2016). Body-mass index and all-cause mortality: individual-participant-data meta-analysis of 239 prospective studies in four continents. *The Lancet*, *388*(10046), 776-786. doi:[http://dx.doi.org/10.1016/S0140-6736\(16\)30175-1](http://dx.doi.org/10.1016/S0140-6736(16)30175-1)
- di Pellegrino, G., Magarelli, S., & Mengarelli, F. (2011). Food pleasantness affects visual selective attention. *Q J Exp Psychol (Hove)*, *64*(3), 560-571. doi:10.1080/17470218.2010.504031
- Doolan, K. J., Breslin, G., Hanna, D., & Gallagher, A. M. (2015). Attentional bias to food-related visual cues: is there a role in obesity? *Proc Nutr Soc*, *74*(1), 37-45. doi:10.1017/s002966511400144x
- Fedoroff, I. D. C., Polivy, J., & Herman, C. P. (1997). The effect of pre-exposure to food cues on the eating behavior of restrained and unrestrained eaters. *Appetite*, *28*(1), 33-47. doi:<http://dx.doi.org/10.1006/appe.1996.0057>
- Fedoroff, I. D. C., Polivy, J., & Herman, C. P. (2003). The specificity of restrained versus unrestrained eaters' responses to food cues: general desire to eat, or craving for the cued food? *Appetite*, *41*(1), 7-13. doi:10.1016/s0195-6663(03)00026-6
- Field, M., Munafò, M. R., & Franken, I. H. A. (2009). A meta-analytic investigation of the relationship between attentional bias and subjective craving in substance abuse. *Psychological Bulletin*, *135*(4), 589-607. doi:10.1037/a0015843
- Field, M., Werthmann, J., Franken, I., Hofmann, W., Hogarth, L., & Roefs, A. (2016). The role of attentional bias in obesity and addiction. *Health Psychol*, *35*(8), 767-780. doi:10.1037/hea0000405
- Folkvord, F., Anschutz, D. J., Wiers, R. W., & Buijzen, M. (2015). The role of attentional bias in the effect of food advertising on actual food intake among children. *Appetite*, *84*, 251-258. doi:10.1016/j.appet.2014.10.016
- Forestell, C. A., Lau, P., Gyurovski, I. I., Dickter, C. L., & Haque, S. S. (2012). Attentional biases to foods: The effects of caloric content and cognitive restraint. *Appetite*, *59*(3), 748-754. doi:10.1016/j.appet.2012.07.006
- Foroni, F., Pergola, G., Argiris, G., & Rumiati, R. (2013). The FoodCast research image database (FRIDa). *Frontiers in Human Neuroscience*, *7*(51). doi:10.3389/fnhum.2013.00051
- Franken, I. H. A. (2003). Drug craving and addiction: integrating psychological and neuropsychopharmacological approaches. *Progress in Neuro-Psychopharmacology and Biological Psychiatry*, *27*(4), 563-579. doi:[http://dx.doi.org/10.1016/S0278-5846\(03\)00081-2](http://dx.doi.org/10.1016/S0278-5846(03)00081-2)
- Gearhardt, A. N., Treat, T. A., Hollingworth, A., & Corbin, W. R. (2012). The relationship between eating-related individual differences and visual attention to foods high in added fat and sugar. *Eating Behaviors*, *13*(4), 371-374. doi:10.1016/j.eatbeh.2012.07.004

- Graham, R., Hoover, A., Ceballos, N. A., & Komogortsev, O. (2011). Body mass index moderates gaze orienting biases and pupil diameter to high and low calorie food images. *Appetite*, *56*(3), 577-586. doi:10.1016/j.appet.2011.01.029
- Gronau, Q. F., Van Erp, S., Heck, D. W., Cesario, J., Jonas, K. J., & Wagenmakers, E.-J. (2017). A Bayesian model-averaged meta-analysis of the power pose effect with informed and default priors: The case of felt power. *Comprehensive Results in Social Psychology*, *2*(1), 123-138.
- Hagan, K. E., Alasmar, A., Exum, A., Chinn, B., & Forbush, K. T. (2020). A systematic review and meta-analysis of attentional bias toward food in individuals with overweight and obesity. *Appetite*, *151*, 104710. doi:10.1016/j.appet.2020.104710
- Hall, K. D. (2018). Did the Food Environment Cause the Obesity Epidemic? *Obesity (Silver Spring)*, *26*(1), 11-13. doi:10.1002/oby.22073
- Hardman, C. A., Rogers, P. J., Etchells, K. A., Houstoun, K. V., & Munafo, M. R. (2013). The effects of food-related attentional bias training on appetite and food intake. *Appetite*, *71*, 295-300. doi:10.1016/j.appet.2013.08.021
- Hardman, C. A., Scott, J., Field, M., & Jones, A. (2014). To eat or not to eat. The effects of expectancy on reactivity to food cues. *Appetite*, *76*, 153-160. doi:10.1016/j.appet.2014.02.005
- Hendrikse, J. J., Cachia, R. L., Kothe, E. J., McPhie, S., Skouteris, H., & Hayden, M. J. (2015). Attentional biases for food cues in overweight and individuals with obesity: a systematic review of the literature. *Obes Rev*, *16*(5), 424-432. doi:10.1111/obr.12265
- Hepworth, R., Mogg, K., Brignell, C., & Bradley, B. P. (2010). Negative mood increases selective attention to food cues and subjective appetite. *Appetite*, *54*(1), 134-142. doi:10.1016/j.appet.2009.09.019
- Hermans, R. C. J., Larsen, J. K., Lochbuehler, K., Nederkoom, C., Herman, C. P., & Engels, R. C. M. E. (2013). The power of social influence over food intake: Examining the effects of attentional bias and impulsivity. *British Journal of Nutrition*, *109*(3), 572-580. doi:10.1017/S0007114512001390
- Hetherington, M. M., & MacDiarmid, J. I. (1993). "Chocolate addiction": a preliminary study of its description and its relationship to problem eating. *Appetite*, *21*(3), 233-246. doi:10.1006/appe.1993.1042
- Higgs, S. (2016). Cognitive processing of food rewards. *Appetite*, *104*, 10-17. doi:10.1016/j.appet.2015.10.003
- Higgs, S., Rutters, F., Thomas, J. M., Naish, K., & Humphreys, G. W. (2012). Top down modulation of attention to food cues via working memory. *Appetite*, *59*(1), 71-75. doi:10.1016/j.appet.2012.03.018
- Higgs, S., Spetter, M. S., Thomas, J. M., Rotshtein, P., Lee, M., Hallschmid, M., & Dourish, C. T. (2017). Interactions between metabolic, reward and cognitive processes in appetite control: Implications for novel weight management therapies. *J Psychopharmacol*, *31*(11), 1460-1474. doi:10.1177/0269881117736917
- Hill, A. J. (2007). The psychology of food craving*: Symposium on 'Molecular mechanisms and psychology of food intake'. *Proceedings of the Nutrition Society*, *66*(2), 277-285.
- Hill, A. J., Weaver, C. F., & Blundell, J. E. (1991). Food craving, dietary restraint and mood. *Appetite*, *17*(3), 187-197.
- Hume, D. J., Howells, F. M., Rauch, H. G. L., Kroff, J., & Lambert, E. V. (2015). Electrophysiological indices of visual food cue-reactivity. Differences in obese, overweight and normal weight women. *Appetite*, *85*, 126-137.
- Jones, A., Christiansen, P., & Field, M. (2018). Failed attempts to improve the reliability of the alcohol visual probe task following empirical recommendations. *Psychol Addict Behav*, *32*(8), 922-932. doi:10.1037/adb0000414
- Kahveci, S., Meule, A., Lender, A., & Blechert, J. (2020). Food approach bias is moderated by the desire to eat specific foods. *Appetite*, *154*, 104758. doi:<https://doi.org/10.1016/j.appet.2020.104758>
- Kaisari, P., Kumar, S., Hattersley, J., Dourish, C. T., Rotshtein, P., & Higgs, S. (2019). Top-down guidance of attention to food cues is enhanced in individuals with

- overweight/obesity and predicts change in weight at one-year follow up. *Int J Obes (Lond)*, 43(9), 1849-1858. doi:10.1038/s41366-018-0246-3
- Kakoschke, N., Kemps, E., & Tiggemann, M. (2014). Attentional bias modification encourages healthy eating. *Eating Behaviors*, 15(1), 120-124. doi:10.1016/j.eatbeh.2013.11.001
- Kavanagh, D. J., Andrade, J., & May, J. (2005). Imaginary relish and exquisite torture: the elaborated intrusion theory of desire. *Psychol Rev*, 112(2), 446-467. doi:10.1037/0033-295x.112.2.446
- Kemps, E., Herman, C. P., Hollitt, S., Polivy, J., Prichard, I., & Tiggemann, M. (2016). Contextual cue exposure effects on food intake in restrained eaters. *Physiology & Behavior*, 167, 71-75. doi:<https://doi.org/10.1016/j.physbeh.2016.09.004>
- Kemps, E., Tiggemann, M., & Hollitt, S. (2014). Biased attentional processing of food cues and modification in obese individuals. *Health Psychology*, 33(11), 1391.
- Kemps, E., Tiggemann, M., Orr, J., & Grear, J. (2014). Attentional retraining can reduce chocolate consumption. *Journal of Experimental Psychology: Applied*, 20(1), 94.
- Kruijt, A.-W., Field, A. P., & Fox, E. (2016). Capturing dynamics of biased attention: are new attention variability measures the way forward? *PLoS ONE*, 11(11), e0166600.
- Lakens, D., McLatchie, N., Isager, P. M., Scheel, A. M., & Dienes, Z. (2020). Improving Inferences About Null Effects With Bayes Factors and Equivalence Tests. *J Gerontol B Psychol Sci Soc Sci*, 75(1), 45-57. doi:10.1093/geronb/gby065
- Lang, P. J., Bradley, M. M., & Cuthbert, B. N. (2013). Motivated attention: Affect, activation, and action. In P. J. Lang, R. F. Simons, M. Balaban, & R. Simons (Eds.), *Attention and orienting: Sensory and motivational processes*. New York: Routledge.
- Langan, D., Higgins, J. P. T., Jackson, D., Bowden, J., Veroniki, A. A., Kontopantelis, E., . . . Simmonds, M. (2019). A comparison of heterogeneity variance estimators in simulated random-effects meta-analyses. *Res Synth Methods*, 10(1), 83-98. doi:10.1002/jrsm.1316
- Lattimore, P., & Mead, B. R. (2015). See it, grab it, or STOP! Relationships between trait impulsivity, attentional bias for pictorial food cues and associated response inhibition following in-vivo food cue exposure. *Appetite*, 90, 248-253. doi:10.1016/j.appet.2015.02.020
- Lavy, E. H., & van den Hout, M. A. (1993). Attentional Bias for Appetitive Cues: Effects of Fasting in Normal Subjects. *Behavioural and Cognitive Psychotherapy*, 21(4), 297-310. doi:10.1017/S1352465800011632
- Littel, M., Euser, A. S., Munafò, M. R., & Franken, I. H. A. (2012). Electrophysiological indices of biased cognitive processing of substance-related cues: A meta-analysis. *Neuroscience & Biobehavioral Reviews*, 36(8), 1803-1816. doi:<http://dx.doi.org/10.1016/j.neubiorev.2012.05.001>
- MacLean, P. S., Blundell, J. E., Mennella, J. A., & Batterham, R. L. (2017). Biological control of appetite: A daunting complexity. *Obesity (Silver Spring)*, 25 Suppl 1, S8-S16. doi:10.1002/oby.21771
- Matheson, G. J. (2019). We need to talk about reliability: making better use of test-retest studies for study design and interpretation. *PeerJ*, 7, e6918-e6918. doi:10.7717/peerj.6918
- May, J., Kavanagh, D. J., & Andrade, J. (2015). The elaborated intrusion theory of desire: a 10-year retrospective and implications for addiction treatments. *Addictive Behaviors*, 44, 29-34.
- Mlinarić, A., Horvat, M., & Šupak Smolčić, V. (2017). Dealing with the positive publication bias: Why you should really publish your negative results. *Biochemia medica*, 27(3), 030201-030201. doi:10.11613/BM.2017.030201
- Nederkorn, C., Smulders, F. T. Y., & Jansen, A. (2000). Cephalic phase responses, craving and food intake in normal subjects. *Appetite*, 35(1), 45-55.
- Neimeijer, R. A. M., Roefs, A., & de Jong, P. J. (2017). Heightened Attentional Capture by Visual Food Stimuli in Anorexia Nervosa. *J Abnorm Psychol*. doi:10.1037/abn0000275

- Nijs, I. M., & Franken, I. H. (2012). Attentional Processing of Food Cues in Overweight and Obese Individuals. *Curr Obes Rep*, 1(2), 106-113. doi:10.1007/s13679-012-0011-1
- Nijs, I. M., Franken, I. H., & Muris, P. (2008). Food cue-elicited brain potentials in obese and healthy-weight individuals. *Eating Behaviors*, 9(4), 462-470.
- Nijs, I. M., Franken, I. H., & Muris, P. (2010). Food-related Stroop interference in obese and normal-weight individuals: Behavioral and electrophysiological indices. *Eating Behaviors*, 11(4), 258-265.
- Nijs, I. M., Muris, P., Euser, A. S., & Franken, I. H. (2010). Differences in attention to food and food intake between overweight/obese and normal-weight females under conditions of hunger and satiety. *Appetite*, 54(2), 243-254.
- O'Neill, A., Bachi, B., & Bhattacharyya, S. (2020). Attentional bias towards cannabis cues in cannabis users: A systematic review and meta-analysis. *Drug and alcohol dependence*, 206, 107719.
- Papies, E. K., Stroebe, W., & Aarts, H. (2008). The allure of forbidden food: On the role of attention in self-regulation. *Journal of Experimental Social Psychology*, 44(5), 1283-1292. doi:<http://dx.doi.org/10.1016/j.jesp.2008.04.008>
- Parsons, S., Kruijt, A., & Fox, E. (2018). Psychological Science needs a standard practice of reporting the reliability of cognitive behavioural measurements. . doi:<https://doi.org/10.31234/osf.io/6ka9z>
- Phaf, R. H., & Kan, K.-J. (2007). The automaticity of emotional Stroop: A meta-analysis. *Journal of Behavior Therapy and Experimental Psychiatry*, 38(2), 184-199.
- Pool, E., Brosch, T., Delplanque, S., & Sander, D. (2016). Attentional bias for positive emotional stimuli: A meta-analytic investigation. *Psychological Bulletin*, 142(1), 79.
- Pothos, E. M., Calitri, R., Tapper, K., Brunstrom, J. M., & Rogers, P. J. (2009). Comparing measures of cognitive bias relating to eating behaviour. *Applied Cognitive Psychology*, 23(7), 936-952. doi:10.1002/acp.1506
- Pothos, E. M., Tapper, K., & Calitri, R. (2009). Cognitive and behavioral correlates of BMI among male and female undergraduate students. *Appetite*, 52(3), 797-800. doi:10.1016/j.appet.2009.03.002
- Powell, D. J., McMinn, D., & Allan, J. L. (2017). Does real time variability in inhibitory control drive snacking behavior? An intensive longitudinal study. *Health Psychol*, 36(4), 356-364. doi:10.1037/hea0000471
- Richard, A., Meule, A., & Blechert, J. (2018). When and how do explicit measures of food craving predict implicit food evaluation? A moderated mediation model. *Food Quality and Preference*, 66, 141-147.
- Robinson, E., Haynes, A., Hardman, C. A., Kemps, E., Higgs, S., & Jones, A. (2017). The bogus taste test: Validity as a measure of laboratory food intake. *Appetite*, 116, 223-231. doi:<https://doi.org/10.1016/j.appet.2017.05.002>
- Robinson, T. E., & Berridge, K. C. (1993). The neural basis of drug craving: an incentive-sensitization theory of addiction. *Brain Research Reviews*, 18, 247-291.
- Robinson, T. E., & Berridge, K. C. (2008). The incentive sensitization theory of addiction: some current issues. *Philosophical Transactions of the Royal Society B: Biological Sciences*, 363(1507), 3137-3146.
- Rodebaugh, T. L., Scullin, R. B., Langer, J. K., Dixon, D. J., Huppert, J. D., Bernstein, A., . . . Lenze, E. J. (2016). Unreliability as a threat to understanding psychopathology: The cautionary tale of attentional bias. *J Abnorm Psychol*, 125(6), 840.
- Rogers, P. J., & Brunstrom, J. M. (2016). Appetite and energy balancing. *Physiol Behav*. doi:10.1016/j.physbeh.2016.03.038
- Rogers, P. J., & Hardman, C. A. (2015). Food reward. What it is and how to measure it. *Appetite*, 90, 1-15. doi:10.1016/j.appet.2015.02.032
- Rogers, P. J., & Smit, H. J. (2000). Food craving and food "addiction": a critical review of the evidence from a biopsychosocial perspective. *Pharmacology, Biochemistry, and Behavior*, 66(1), 3-14.
- Rolls, B. J., Rolls, E. T., Rowe, E. A., & Sweeney, K. (1981). Sensory specific satiety in man. *Physiol Behav*, 27(1), 137-142.

- Rosenheck, R. (2008). Fast food consumption and increased caloric intake: a systematic review of a trajectory towards weight gain and obesity risk. *Obes Rev*, 9(6), 535-547. doi:10.1111/j.1467-789X.2008.00477.x
- Ruddock, H. K., Dickson, J. M., Field, M., & Hardman, C. A. (2015). Eating to live or living to eat? Exploring the causal attributions of self-perceived food addiction. *Appetite*, 95, 262-268. doi:10.1016/j.appet.2015.07.018
- Smith, K. E., Mason, T. B., Juarascio, A., Weinbach, N., Dvorak, R., Crosby, R. D., & Wonderlich, S. A. (2020). The momentary interplay of affect, attention bias, and expectancies as predictors of binge eating in the natural environment. *Int J Eat Disord*, 53(4), 586-594. doi:10.1002/eat.23235
- Stojek, M., Shank, L. M., Vannucci, A., Bongiorno, D. M., Nelson, E. E., Waters, A. J., . . . Tanofsky-Kraff, M. (2018). A systematic review of attentional biases in disorders involving binge eating. *Appetite*, 123, 367-389. doi:10.1016/j.appet.2018.01.019
- Tapper, K., Pothos, E. M., & Lawrence, A. D. (2010). Feast your eyes: hunger and trait reward drive predict attentional bias for food cues. *Emotion*, 10(6), 949.
- Thornton, A., & Lee, P. (2000). Publication bias in meta-analysis: its causes and consequences. *Journal of Clinical Epidemiology*, 53(2), 207-216. doi:[https://doi.org/10.1016/S0895-4356\(99\)00161-4](https://doi.org/10.1016/S0895-4356(99)00161-4)
- Treue, S. (2003). Visual attention: the where, what, how and why of saliency. *Current opinion in neurobiology*, 13(4), 428-432.
- Turton, R., Bruidegom, K., Cardi, V., Hirsch, C. R., & Treasure, J. (2016). Novel methods to help develop healthier eating habits for eating and weight disorders: A systematic review and meta-analysis. *Neurosci Biobehav Rev*, 61, 132-155. doi:10.1016/j.neubiorev.2015.12.008
- van Ens, W., Schmidt, U., Campbell, I. C., Roefs, A., & Werthmann, J. (2019). Test-retest reliability of attention bias for food: Robust eye-tracking and reaction time indices. *Appetite*, 136, 86-92. doi:<https://doi.org/10.1016/j.appet.2019.01.020>
- Wang, Y. C., McPherson, K., Marsh, T., Gortmaker, S. L., & Brown, M. (2011). Health and economic burden of the projected obesity trends in the USA and the UK. *The Lancet*, 378(9793), 815-825. doi:[http://dx.doi.org/10.1016/S0140-6736\(11\)60814-3](http://dx.doi.org/10.1016/S0140-6736(11)60814-3)
- Weierich, M. R., Treat, T. A., & Hollingworth, A. (2008). Theories and measurement of visual attentional processing in anxiety. *Cognition and Emotion*, 22(6), 985-1018.
- Werthmann, J., Field, M., Roefs, A., Nederkoom, C., & Jansen, A. (2014). Attention bias for chocolate increases chocolate consumption - An attention bias modification study. *Journal of Behavior Therapy and Experimental Psychiatry*, 45(1), 136-143. doi:10.1016/j.jbtep.2013.09.009
- Werthmann, J., Jansen, A., & Roefs, A. (2015). Worry or craving? A selective review of evidence for food-related attention biases in obese individuals, eating-disorder patients, restrained eaters and healthy samples. *Proc Nutr Soc*, 74(2), 99-114. doi:10.1017/s0029665114001451
- Werthmann, J., Jansen, A., & Roefs, A. (2016). Make up your mind about food: A healthy mindset attenuates attention for high-calorie food in restrained eaters. *Appetite*, 105, 53-59. doi:10.1016/j.appet.2016.05.005
- Werthmann, J., Jansen, A., Vreugdenhil, A. C. E., Nederkoom, C., Schyns, G., & Roefs, A. (2015). Food Through the Child's Eye: An Eye-Tracking Study on Attentional Bias for Food in Healthy-Weight Children and Children With Obesity. *Health Psychology*. doi:10.1037/hea0000225
- Werthmann, J., Renner, F., Roefs, A., Huibers, M. J. H., Plumanns, L., Krott, N., & Jansen, A. (2014). Looking at food in sad mood: Do attention biases lead emotional eaters into overeating after a negative mood induction? *Eating Behaviors*, 15(2), 230-236. doi:10.1016/j.eatbeh.2014.02.001
- Werthmann, J., Roefs, A., Nederkoom, C., & Jansen, A. (2013). Desire lies in the eyes: Attention bias for chocolate is related to craving and self-endorsed eating permission. *Appetite*, 70, 81-89. doi:10.1016/j.appet.2013.06.087

- Werthmann, J., Roefs, A., Nederkoorn, C., Mogg, K., Bradley, B. P., & Jansen, A. (2011). Can(not) Take my Eyes off it: Attention Bias for Food in Overweight Participants. *Health Psychology, 30*(5), 561-569. doi:10.1037/a0024291
- Werthmann, J., Roefs, A., Nederkoorn, C., Mogg, K., Bradley, B. P., & Jansen, A. (2013). Attention bias for food is independent of restraint in healthy weight individuals-An eye tracking study. *Eating Behaviors, 14*(3), 397-400. doi:10.1016/j.eatbeh.2013.06.005
- Yiend, J. (2010). The effects of emotion on attention: A review of attentional processing of emotional information. *Cognition and Emotion, 24*(1), 3-47. doi:10.1080/02699930903205698
- Zvielli, A., Bernstein, A., & Koster, E. H. W. (2015). Temporal dynamics of attentional bias. *Clinical Psychological Science, 3*(5), 772-788.

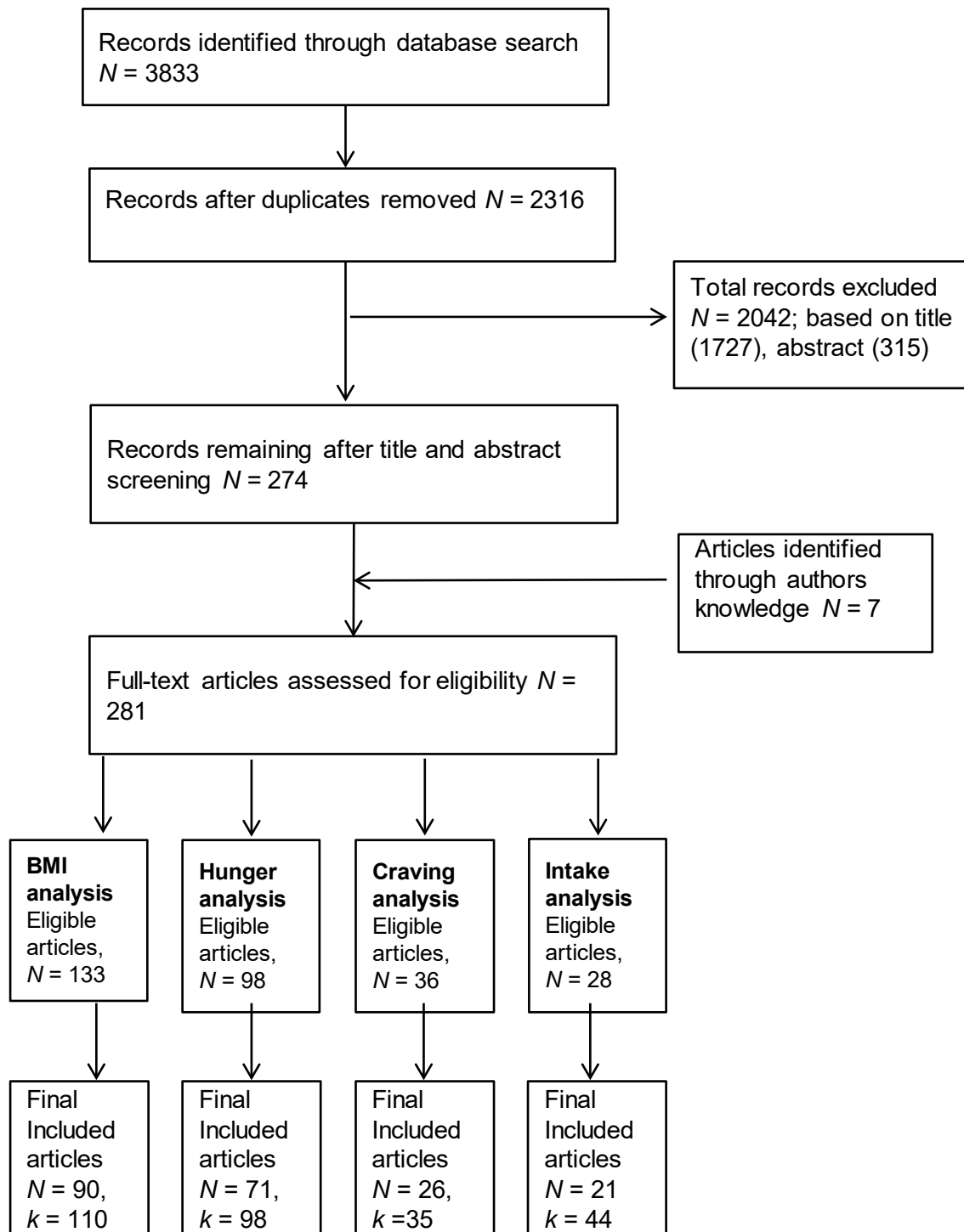


Figure 1. PRISMA diagram to show the process of inclusion and exclusion of studies in the meta-analyses following the three waves of literature searches (i.e. in 2015, 2018, and 2019).

N = number of articles, k = number of effect sizes drawn from these articles.

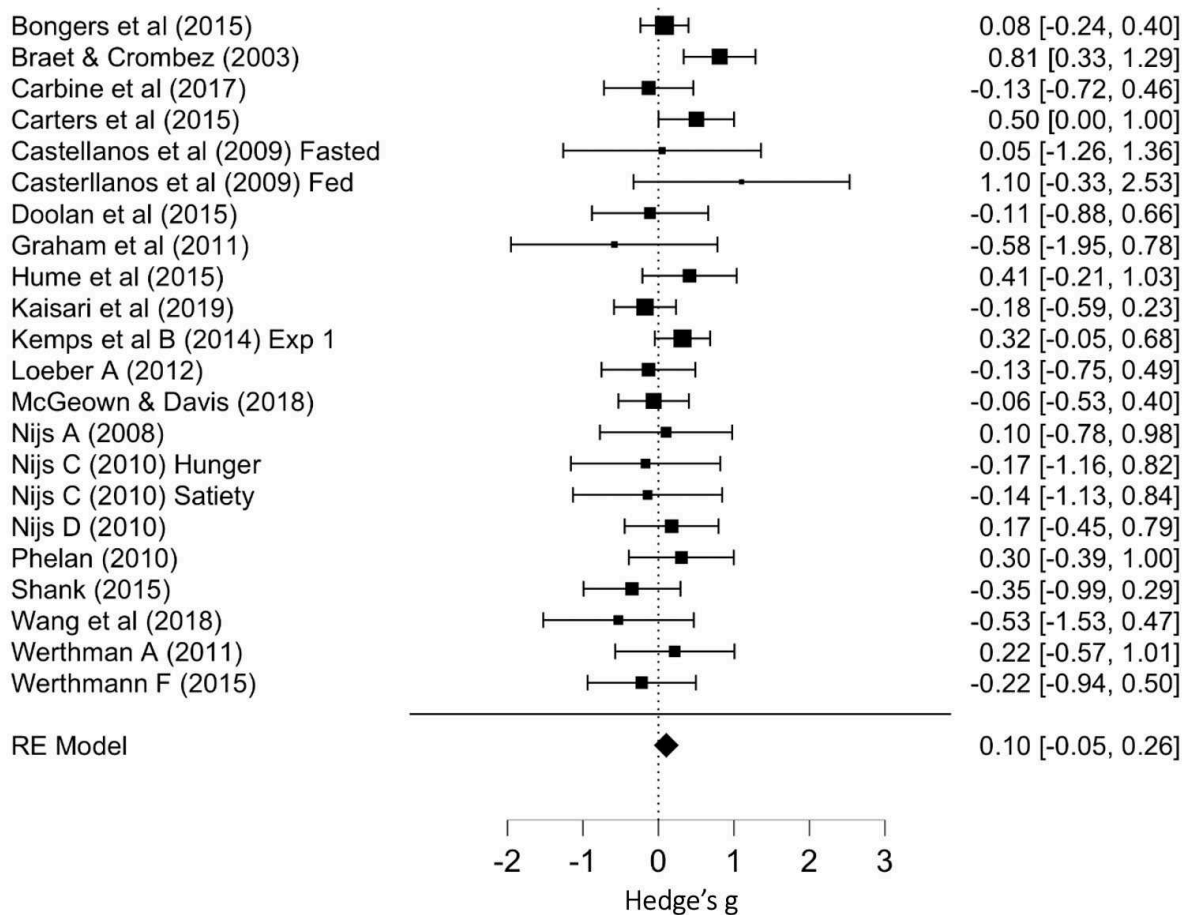


Figure 2. Forest plot of food-related AB in studies which compared participants with overweight/obesity to healthy weight control groups

Note. The dashed vertical line represents no effect (i.e., Hedge's $g = 0$). Individual study effect sizes are shown with 95% confidence intervals of each study's effect size. The size of each black box is proportionate to the weight of the study. The overall effect size, and 95% confidence interval of the effect size, computed from individual studies is shown at the bottom of the figure. A positive Hedge's g indicates increased attentional bias in the group with overweight /obesity relative to the healthy weight control group.

References of articles include in the meta-analyses

Note: Where a first author has multiple included articles, letters have been used to distinguish these in the associated Excel data spreadsheets. Where relevant, the coding of these is detailed in bold in the below list of references.

- Ahern, A. L., Field, M., Yokum, S., Bohon, C., & Stice, E. (2010). Relation of dietary restraint scores to cognitive biases and reward sensitivity. *Appetite*, *55*(1), 61-68.
doi:10.1016/j.appet.2010.04.001
- Bazzaz, M. M., Fadardi, J. S., & Parkinson, J. (2017). Efficacy of the attention control training program on reducing attentional bias in obese and overweight dieters. *Appetite*, *108*, 1-11. doi:10.1016/j.appet.2016.08.114
- Benau, E. M., & Moelter, S. T. (2016). The content of lexical stimuli and self-reported physiological state modulate error-related negativity amplitude. *Physiology & behavior*, *163*, 43-50. doi:10.1016/j.physbeh.2016.04.036
- Blechert, J., Feige, B., Hajcak, G., & Tuschen-Caffier, B. (2010). To eat or not to eat? Availability of food modulates the electrocortical response to food pictures in restrained eaters. *Appetite*, *54*(2), 262-268. doi:10.1016/j.appet.2009.11.007
- Bongers, P., van de Giessen, E., Roefs, A., Nederkoorn, C., Booij, J., van den Brink, W., & Jansen, A. (2014). Being Impulsive and Obese Increases Susceptibility to Speeded Detection of High-Calorie Foods. *Health Psychol.* doi:10.1037/hea0000167
- Boutelle, K. N., Kuckertz, J. M., Carlson, J., & Amir, N. (2014). A pilot study evaluating a one-session attention modification training to decrease overeating in obese children. *Appetite*, *76*, 180-185. doi:10.1016/j.appet.2014.01.075
- Boutelle, K. N., Monreal, T., Strong, D. R., & Amir, N. (2016). An open trial evaluating an attention bias modification program for overweight adults who binge eat. *Journal Of Behavior Therapy And Experimental Psychiatry*, *52*, 138-146.
doi:10.1016/j.jbtep.2016.04.005
- Braet, C., & Crombez, G. (2003). Cognitive interference due to food cues in childhood obesity. *Journal of Clinical Child and Adolescent Psychology*, *32*(1), 32-39.
doi:10.1207/15374420360533040
- Brignell, C., Griffiths, T., Bradley, B. P., & Mogg, K. (2009). Attentional and approach biases for pictorial food cues. Influence of external eating. *Appetite*, *52*(2), 299-306.
doi:10.1016/j.appet.2008.10.007
- Brockmeyer, T., Hahn, C., Reetz, C., Schmidt, U., & Friederich, H.-C. (2015). Approach Bias Modification in Food Craving-A Proof-of-Concept Study. *European eating disorders review : the journal of the Eating Disorders Association*, *23*(5), 352-360.
doi:10.1002/erv.2382
- Brody, S., Keller, U., Degen, L., Cox, D. J., & Schächinger, H. (2004). Selective processing of food words during insulin-induced hypoglycemia in healthy humans. *Psychopharmacology*, *173*(1), 217-220. doi:10.1007/s00213-003-1722-5
- Carbine, K. A., Larson, M. J., Romney, L., Bailey, B. W., Tucker, L. A., Christensen, W. F., & LeCheminant, J. D. (2017). Disparity in neural and subjective responses to food images in women with obesity and normal-weight women. *Obesity (Silver Spring, Md.)*, *25*(2), 384-390. doi:10.1002/oby.21710
- Carretié, L., Mercado, F., & Tapia, M. (2000). Parietal ERP Activity and Appetite. *Motivation and Emotion*, *24*(1), 1-12.
- Carters, M. A., Rieger, E., & Bell, J. (2015). Reduced Inhibition of Return to Food Images in Obese Individuals. *PLoS ONE*, *10*(9), e0137821-e0137821.
doi:10.1371/journal.pone.0137821
- Castellanos, E. H., Charboneau, E., Dietrich, M. S., Park, S., Bradley, B. P., Mogg, K., & Cowan, R. L. (2009). Obese adults have visual attention bias for food cue images: evidence for altered reward system function. *International Journal of Obesity*, *33*(9), 1063-1073. doi:10.1038/ijo.2009.138

- De Oca, B. M., & Black, A. A. (2013). Bullets versus burgers: Is it threat or relevance that captures attention? *American Journal of Psychology*, *126*(3), 287-300. doi:10.5406/amerjpsyc.126.3.0287
- Demos, K. E., McCaffery, J. M., Cournoyer, S. A., Wunsch, C. A., & Wing, R. R. (2013). Greater Food-Related Stroop Interference Following Behavioral Weight Loss Intervention. *J Obes Weight Loss Ther*, *3*. doi:10.4172/2165-7904.1000187
- Doolan, K. J., Breslin, G., Hanna, D., Murphy, K., & Gallagher, A. M. (2014). Visual attention to food cues in obesity: an eye-tracking study. *Obesity (Silver Spring)*, *22*(12), 2501-2507. doi:10.1002/oby.20884
- Folkvord, F., Anschutz, D. J., Wiers, R. W., & Buijzen, M. (2015). The role of attentional bias in the effect of food advertising on actual food intake among children. *Appetite*, *84*, 251-258. doi:10.1016/j.appet.2014.10.016
- Forestell, C. A., Lau, P., Gyurovski, I. I., Dickter, C. L., & Haque, S. S. (2012). Attentional biases to foods: The effects of caloric content and cognitive restraint. *Appetite*, *59*(3), 748-754. doi:10.1016/j.appet.2012.07.006
- Frayn, M., Sears, C. R., & von Ranson, K. M. (2016). A sad mood increases attention to unhealthy food images in women with food addiction. *Appetite*, *100*, 55-63. doi:10.1016/j.appet.2016.02.008
- Freijy, T., Mullan, B., & Sharpe, L. (2014). Food-related attentional bias. Word versus pictorial stimuli and the importance of stimuli calorific value in the dot probe task. *Appetite*, *83*, 202-208. doi:10.1016/j.appet.2014.08.037
- Garcia-Burgos, D., Lao, J., Munsch, S., & Caldara, R. (2017). Visual attention to food cues is differentially modulated by gustatory-hedonic and post-ingestive attributes. *Food Research International*, *97*, 199-208. doi:10.1016/j.foodres.2017.04.011
- Gearhardt, A. N., Treat, T. A., Hollingworth, A., & Corbin, W. R. (2012). The relationship between eating-related individual differences and visual attention to foods high in added fat and sugar. *Eating Behaviors*, *13*(4), 371-374. doi:10.1016/j.eatbeh.2012.07.004
- Gendle, M. H., & Finnegan, E. E. (2007). Self-imposed dietary restraint and food stroop performance in college-age women. *Journal of the North Carolina Academy of Science*, *123*(1), 49-59.
- Giel, K. E., Rieber, N., Enck, P., Friederich, H. C., Meile, T., Zipfel, S., & Teufel, M. (2014). Effects of laparoscopic sleeve gastrectomy on attentional processing of food-related information: Evidence from eye-tracking. *Surgery for Obesity and Related Diseases*, *10*(2), 277-282. doi:10.1016/j.soard.2013.09.012
- Graham, R., Hoover, A., Ceballos, N. A., & Komogortsev, O. (2011). Body mass index moderates gaze orienting biases and pupil diameter to high and low calorie food images. *Appetite*, *56*(3), 577-586. doi:10.1016/j.appet.2011.01.029
- Hardman, C. A., Rogers, P. J., Etchells, K. A., Houstoun, K. V., & Munafo, M. R. (2013). The effects of food-related attentional bias training on appetite and food intake. *Appetite*, *71*, 295-300. doi:10.1016/j.appet.2013.08.021
- Hardman, C. A., Scott, J., Field, M., & Jones, A. (2014). To eat or not to eat. The effects of expectancy on reactivity to food cues. *Appetite*, *76*, 153-160. doi:10.1016/j.appet.2014.02.005
- Hepworth, R., Mogg, K., Brignell, C., & Bradley, B. P. (2010). Negative mood increases selective attention to food cues and subjective appetite. *Appetite*, *54*(1), 134-142. doi:10.1016/j.appet.2009.09.019
- Hermans, R. C. J., Larsen, J. K., Lochbuehler, K., Nederkoom, C., Herman, C. P., & Engels, R. C. M. E. (2013). The power of social influence over food intake: Examining the effects of attentional bias and impulsivity. *British Journal of Nutrition*, *109*(3), 572-580. doi:10.1017/S0007114512001390
- Higgs, S., Dolmans, D., Humphreys, G. W., & Rutters, F. (2015). Dietary self-control influences top-down guidance of attention to food cues. *Frontiers in Psychology*, *6*, 427.

- Higgs, S., Rutters, F., Thomas, J. M., Naish, K., & Humphreys, G. W. (2012). Top down modulation of attention to food cues via working memory. *Appetite*, *59*(1), 71-75. doi:10.1016/j.appet.2012.03.018
- Hill, C., Wu, J., Crowley, M. J., & Fearon, P. (2013). Restrictive feeding practices and adiposity are differentially related to P3b cortical responses to food stimuli in children. *Appetite*, *63*, 7-17. doi:10.1016/j.appet.2012.11.025
- Hollitt, S., Kemps, E., Tiggemann, M., Smeets, E., & Mills, J. S. (2010). Components of attentional bias for food cues among restrained eaters. *Appetite*, *54*(2), 309-313. doi:10.1016/j.appet.2009.12.005
- Hou, R., Mogg, K., Bradley, B. P., Moss-Morris, R., Peveler, R., & Roefs, A. (2011). External eating, impulsivity and attentional bias to food cues. *Appetite*, *56*(2), 424-427. doi:10.1016/j.appet.2011.01.019
- Hume, D. J., Howells, F. M., Karpul, D., Rauch, H. G. L., Kroff, J., & Lambert, E. V. (2015). Cognitive control over visual food cue saliency is greater in reduced-overweight/obese but not in weight relapsed women: An EEG study. *Eating Behaviors*, *19*, 76-80. doi:10.1016/j.eatbeh.2015.06.013
- Hummel, G., Zerweck, I., Ehret, J., Salazar Winter, S., & Stroebele-Benschop, N. (2017). The influence of the arrangement of different food images on participants' attention: An experimental eye-tracking study. *Food Quality and Preference*, *62*, 111-119. doi:10.1016/j.foodqual.2017.07.003
- Janssen, L. K., Duif, I., van Loon, I., Wegman, J., de Vries, J. H. M., Cools, R., & Aarts, E. (2017). Loss of lateral prefrontal cortex control in food-directed attention and goal-directed food choice in obesity. *NeuroImage*, *146*, 148-156. doi:10.1016/j.neuroimage.2016.11.015
- Jones, A., Hogarth, L., Christiansen, P., Rose, A. K., Martinovic, J., & Field, M. (2012). Reward expectancy promotes generalized increases in attentional bias for rewarding stimuli. *Quarterly Journal of Experimental Psychology*, *65*(12), 2333-2342. doi:10.1080/17470218.2012.686513
- Kaisari, P., Kumar, S., Hattersley, J., Dourish, C. T., Rotshtein, P., & Higgs, S. (2019). Top-down guidance of attention to food cues is enhanced in individuals with overweight/obesity and predicts change in weight at one-year follow up. *International Journal of Obesity*, *43*(9), 1849-1858.
- Kakoschke, N., Kemps, E., & Tiggemann, M. (2014). Attentional bias modification encourages healthy eating. *Eating Behaviors*, *15*(1), 120-124. doi:10.1016/j.eatbeh.2013.11.001
- Kakoschke, N., Kemps, E., & Tiggemann, M. (2015). Combined effects of cognitive bias for food cues and poor inhibitory control on unhealthy food intake. *Appetite*, *87*, 358-364. doi:10.1016/j.appet.2015.01.004
- Kemps, E., & Tiggemann, M. (2009). Attentional Bias for Craving-Related (Chocolate) Food Cues. *Experimental and Clinical Psychopharmacology*, *17*(6), 425-433. doi:10.1037/a0017796 **Kemps et al A (2009)**.
- Kemps, E., Tiggemann, M., & Elford, J. (2015). Sustained effects of attentional re-training on chocolate consumption. *J Behav Ther Exp Psychiatry*. doi:10.1016/j.jbtep.2014.12.001 **Kemps et al D (2015)**.
- Kemps, E., Tiggemann, M., & Hollitt, S. (2014). Biased attentional processing of food cues and modification in obese individuals. *Health Psychology*, *33*(11), 1391-1401. doi:10.1037/hea0000069 **Kemps et al B (2014)**
- Kemps, E., Tiggemann, M., & Hollitt, S. (2016). Longevity of attentional bias modification effects for food cues in overweight and obese individuals. *Psychology & health*, *31*(1), 115-129. doi:10.1080/08870446.2015.1077251 **Kemps et al E (2016)**
- Kemps, E., Tiggemann, M., Orr, J., & Grear, J. (2014). Attentional retraining can reduce chocolate consumption. *Journal of Experimental Psychology: Applied*, *20*(1), 94-102. doi:10.1037/xap0000005 **Kemps et al C (2014)**

- Kemps, E., Tiggemann, M., & Stewart-Davis, E. (2018). Can attentional bias modification inoculate people to withstand exposure to real-world food cues? *Appetite*, *120*, 222-229. doi:10.1016/j.appet.2017.09.003 **Kemps et al F (2018)**
- Kirsten, H., Seib-Pfeifer, L.-E., Koppehele-Gossel, J., & Gibbons, H. (2019). Food has the right of way: Evidence for prioritised processing of visual food stimuli irrespective of eating style. *Appetite*, *142*, 104372.
- Kleiman, T., Trope, Y., & Amodio, D. M. (2016). Cognitive control modulates attention to food cues: Support for the control readiness model of self-control. *Brain and cognition*, *110*, 94-101. doi:10.1016/j.bandc.2016.04.006
- Koopman, K. E., Roefs, A., Elbers, D. C. E., Fliers, E., Booij, J., Serlie, M. J., & la Fleur, S. E. (2016). Brain dopamine and serotonin transporter binding are associated with visual attention bias for food in lean men. *Psychological medicine*, *46*(8), 1707-1717. doi:10.1017/s0033291716000222
- Kumar, S., Higgs, S., Rutters, F., & Humphreys, G. W. (2016). Biased towards food: Electrophysiological evidence for biased attention to food stimuli. *Brain and cognition*, *110*, 85-93. doi:10.1016/j.bandc.2016.04.007
- Lattimore, P., & Mead, B. R. (2015). See it, grab it, or STOP! Relationships between trait impulsivity, attentional bias for pictorial food cues and associated response inhibition following in-vivo food cue exposure. *Appetite*, *90*, 248-253. doi:10.1016/j.appet.2015.02.020
- Loeber, S., Grosshans, M., Herpertz, S., Kiefer, F., & Herpertz, S. C. (2013). Hunger modulates behavioral disinhibition and attention allocation to food-associated cues in normal-weight controls. *Appetite*, *71*, 32-39. doi:10.1016/j.appet.2013.07.008
- Loeber, S., Grosshans, M., Korucuoglu, O., Vollmert, C., Vollstaedt-Klein, S., Schneider, S., . . . Kiefer, F. (2012). Impairment of inhibitory control in response to food-associated cues and attentional bias of obese participants and normal-weight controls. *International Journal of Obesity*, *36*(10), 1334-1339. doi:10.1038/ijo.2011.184
- Maas, J., Keijsers, G. P., Rinck, M., Tanis, J., & Becker, E. S. (2014). Does a dieting goal affect automatic cognitive processes and their trainability? *Cognitive Therapy and Research* Dec(Pagination), No Pagination Specified.
- McGeown, L., & Davis, R. (2018). Frontal EEG asymmetry moderates the association between attentional bias towards food and body mass index. *Biological Psychology*, *136*, 151-160.
- Mehl, N., Bergmann, S., Klein, A. M., Daum, M., von Klitzing, K., & Horstmann, A. (2017). Cause or consequence? Investigating attention bias and self-regulation skills in children at risk for obesity. *Journal of experimental child psychology*, *155*, 113-127. doi:10.1016/j.jecp.2016.11.003
- Meule, A., Kübler, A., & Blechert, J. (2013). Time course of electrocortical food-cue responses during cognitive regulation of craving. *Frontiers in Psychology*, *4*(SEP). doi:10.3389/fpsyg.2013.00669
- Meule, A., & Platte, P. (2016). Attentional bias toward high-calorie food-cues and trait motor impulsivity interactively predict weight gain. *Health Psychology Open*, *3*(1). doi:10.1177/2055102916649585
- Meule, A., Vögele, C., & Kübler, A. (2012). Restrained eating is related to accelerated reaction to high caloric foods and cardiac autonomic dysregulation. *Appetite*, *58*(2), 638-644. doi:10.1016/j.appet.2011.11.023
- Neimeijer, R. A. M., de Jong, P. J., & Roefs, A. (2013). Temporal attention for visual food stimuli in restrained eaters. *Appetite*, *64*, 5-11. doi:10.1016/j.appet.2012.12.013
- Newman, E., O'Connor, D. B., & Conner, M. (2008). Attentional biases for food stimuli in external eaters: Possible mechanism for stress-induced eating? *Appetite*, *51*(2), 339-342. doi:10.1016/j.appet.2008.03.007
- Nijs, I. M., Franken, I. H., & Muris, P. (2009). Enhanced processing of food-related pictures in female external eaters. *Appetite*, *53*(3), 376-383. doi:10.1016/j.appet.2009.07.022 **Nijs et al B (2009)**

- Nijs, I. M., Franken, I. H. A., & Muris, P. (2008). Food cue-elicited brain potentials in obese and healthy-weight individuals. *Eating Behaviors*, *9*(4), 462-470. doi:10.1016/j.eatbeh.2008.07.009 **Nijs et al A (2008)**
- Nijs, I. M., Franken, I. H. A., & Muris, P. (2010). Food-related Stroop interference in obese and normal-weight individuals: Behavioral and electrophysiological indices. *Eating Behaviors*, *11*(4), 258-265. doi:10.1016/j.eatbeh.2010.07.002 **Nijs et al D (2010)**
- Nijs, I. M., Muris, P., Euser, A. S., & Franken, I. H. (2010). Differences in attention to food and food intake between overweight/obese and normal-weight females under conditions of hunger and satiety. *Appetite*, *54*(2), 243-254. doi:10.1016/j.appet.2009.11.004 **Nijs et al C (2010)**
- Nummenmaa, L., Hietanen, J. K., Calvo, M. G., & Hyönä, J. (2011). Food catches the eye but not for everyone: A BMI-contingent attentional bias in rapid detection of nutrients. *PLoS ONE*, *6*(5). doi:10.1371/journal.pone.0019215
- Oh, H., & Taylor, A. H. (2013). A brisk walk, compared with being sedentary, reduces attentional bias and chocolate cravings among regular chocolate eaters with different body mass. *Appetite*, *71*, 144-149. doi:10.1016/j.appet.2013.07.015
- Oh, H., & Taylor, A. H. (2014). Self-regulating smoking and snacking through physical activity. *Health Psychology*, *33*(4), 349.
- Phelan, S., Hassenstab, J., McCaffery, J. M., Sweet, L., Raynor, H. A., Cohen, R. A., & Wing, R. R. (2011). Cognitive interference from food cues in weight loss maintainers, normal weight, and obese individuals. *Obesity*, *19*(1), 69-73. doi:10.1038/oby.2010.138
- Pollert, G. A., & Veilleux, J. C. (2018). Attentional bias is more predictive of eating behavior after self-control exertion. *Eating Behaviors*, *29*, 25-27. doi:10.1016/j.eatbeh.2018.02.001
- Popien, A., Frayn, M., von Ranson, K. M., & Sears, C. R. (2015). Eye gaze tracking reveals heightened attention to food in adults with binge eating when viewing images of real-world scenes. *Appetite*, *91*, 233-240. doi:10.1016/j.appet.2015.04.046
- Pothos, E. M., Calitri, R., Tapper, K., Brunstrom, J. M., & Rogers, P. J. (2009). Comparing measures of cognitive bias relating to eating behaviour. *Applied Cognitive Psychology*, *23*(7), 936-952. doi:10.1002/acp.1506
- Ruddock, H. K., Field, M., Jones, A., & Hardman, C. A. (2018). State and trait influences on attentional bias to food-cues: The role of hunger, expectancy, and self-perceived food addiction. *Appetite*, *131*, 139-147. doi:10.1016/j.appet.2018.08.038
- Rutters, F., Kumar, S., Higgs, S., & Humphreys, G. W. (2015). Electrophysiological evidence for enhanced representation of food stimuli in working memory. *Experimental Brain Research*, *233*(2), 519-528.
- Sarlo, M., Ubel, S., Leutgeb, V., & Schienle, A. (2013). Cognitive reappraisal fails when attempting to reduce the appetitive value of food: an ERP study. *Biol Psychol*, *94*(3), 507-512. doi:10.1016/j.biopsycho.2013.09.006
- Sawada, R., Sato, W., Minemoto, K., & Fushiki, T. (2019). Hunger promotes the detection of high-fat food. *Appetite*, *142*, 104377.
- Sawada, R., Sato, W., Toichi, M., & Fushiki, T. (2017). Fat content modulates rapid detection of food: A visual search study using fast food and Japanese diet. *Frontiers in Psychology*, *8*(JUN). doi:10.3389/fpsyg.2017.01033
- Schwab, D., Giraldo, M., Spiegl, B., & Schienle, A. (2017). Disgust evoked by strong wormwood bitterness influences the processing of visual food cues in women: An ERP study. *Appetite*, *108*, 51-56. doi:10.1016/j.appet.2016.09.023
- Shank, L. M., Tanofsky-Kraff, M., Nelson, E. E., Shomaker, L. B., Ranzenhofer, L. M., Hannallah, L. M., . . . Yanovski, J. A. (2015). Attentional bias to food cues in youth with loss of control eating. *Appetite*, *87*, 68-75. doi:10.1016/j.appet.2014.11.027
- Svaldi, J., Tuschen-Caffier, B., Biehl, S. C., Gschwendtner, K., Wolz, I., & Naumann, E. (2015). Effects of two cognitive regulation strategies on the processing of food cues in high restrained eaters. An event-related potential study. *Appetite*, *92*, 269-277. doi:10.1016/j.appet.2015.05.026

- Tapper, K., Pothos, E. M., Fadardi, J. S., & Ziori, E. (2008). Restraint, disinhibition and food-related processing bias. *Appetite*, *51*(2), 335-338. doi:10.1016/j.appet.2008.03.006
- Tapper, K., Pothos, E. M., & Lawrence, A. D. (2010). Feast your eyes: hunger and trait reward drive predict attentional bias for food cues. *Emotion*, *10*(6), 949-954. doi:10.1037/a0020305
- van Dillen, L. F., & Andrade, J. (2016). Derailing the streetcar named desire. Cognitive distractions reduce individual differences in cravings and unhealthy snacking in response to palatable food. *Appetite*, *96*, 102-110. doi:10.1016/j.appet.2015.09.013
- van Ens, W., Schmidt, U., Campbell, I. C., Roefs, A., & Werthmann, J. (2019). Test-retest reliability of attention bias for food: Robust eye-tracking and reaction time indices. *Appetite*, *136*, 86-92. doi:https://doi.org/10.1016/j.appet.2019.01.020
- Veenstra, E. M., de Jong, P. J., Koster, E. H. W., & Roefs, A. (2010). Attentional avoidance of high-fat food in unsuccessful dieters. *Journal of Behavior Therapy and Experimental Psychiatry*, *41*(3), 282-288. doi:http://dx.doi.org/10.1016/j.jbtep.2010.02.006
- Verbeken, S., Braet, C., Naets, T., Houben, K., & Boendermaker, W. (2018). Computer training of attention and inhibition for youngsters with obesity: A pilot study. *Appetite*, *123*, 439-447. doi:10.1016/j.appet.2017.12.029
- Wang, E., Cakmak, Y. O., & Peng, M. (2018). Eating with eyes – Comparing eye movements and food choices between overweight and lean individuals in a real-life buffet setting. *Appetite*, *125*, 152-159. doi:10.1016/j.appet.2018.02.003
- Warschburger, P., Gmeiner, M., Morawietz, M., & Rinck, M. (2018). Evaluation of an approach-avoidance training intervention for children and adolescents with obesity: A randomized placebo-controlled prospective trial. *European Eating Disorders Review*, *26*(5), 472-482.
- Werthmann, J., Field, M., Roefs, A., Nederkoorn, C., & Jansen, A. (2014). Attention bias for chocolate increases chocolate consumption - An attention bias modification study. *Journal of Behavior Therapy and Experimental Psychiatry*, *45*(1), 136-143. doi:10.1016/j.jbtep.2013.09.009 **Werthmann et al E (2014)**
- Werthmann, J., Jansen, A., & Roefs, A. (2016). Make up your mind about food: A healthy mindset attenuates attention for high-calorie food in restrained eaters. *Appetite*, *105*. doi:10.1016/j.appet.2016.05.005 **Werthmann et al G (2016)**
- Werthmann, J., Renner, F., Roefs, A., Huibers, M. J. H., Plumanns, L., Krott, N., & Jansen, A. (2014). Looking at food in sad mood: Do attention biases lead emotional eaters into overeating after a negative mood induction? *Eating Behaviors*, *15*(2), 230-236. doi:10.1016/j.eatbeh.2014.02.001 **Werthmann et al D (2014)**
- Werthmann, J., Roefs, A., Nederkoorn, C., & Jansen, A. (2013). Desire lies in the eyes: Attention bias for chocolate is related to craving and self-endorsed eating permission. *Appetite*, *70*, 81-89. doi:10.1016/j.appet.2013.06.087 **Werthmann et al C (2013)**
- Werthmann, J., Roefs, A., Nederkoorn, C., Mogg, K., Bradley, B. P., & Jansen, A. (2011). Can(not) Take my Eyes off it: Attention Bias for Food in Overweight Participants. *Health Psychology*, *30*(5), 561-569. doi:10.1037/a0024291 **Werthmann et al A (2011)**
- Werthmann, J., Roefs, A., Nederkoorn, C., Mogg, K., Bradley, B. P., & Jansen, A. (2013). Attention bias for food is independent of restraint in healthy weight individuals-An eye tracking study. *Eating Behaviors*, *14*(3), 397-400. doi:10.1016/j.eatbeh.2013.06.005 **Werthmann et al B (2013)**
- Werthmann, J., Vreugdenhil, A. C. E., Jansen, A., Nederkoorn, C., Schyns, G., & Roefs, A. (2015). Food Through the Child's Eye: An Eye-Tracking Study on Attentional Bias for Food in Healthy-Weight Children and Children With Obesity. *Health Psychology*, *34*(12). doi:10.1037/hea0000225 **Werthmann et al F (2015)**
- Wu, J., Willner, C. J., Hill, C., Fearon, P., Mayes, L. C., & Crowley, M. J. (2018). Emotional eating and instructed food-cue processing in adolescents: An ERP study. *Biological Psychology*, *132*, 27-36. doi:10.1016/j.biopsycho.2017.10.012