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State and trait influences on attentional bias to food-cues: The role of hunger, expectancy, and self-perceived food addiction

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Abstract

Food-related attentional bias (AB) varies both between individuals (i.e. trait differences) and within individuals (i.e. state differences), as a function of a food's momentary incentive value. People with self-perceived food addiction (SPFA) find food particularly rewarding and may therefore demonstrate increased AB to food-related cues, relative to those who do not perceive themselves as food addicts. However, these trait differences may interact with *state* factors, such as hunger and the perceived availability of food, to differentially affect AB to food-cues. In the current study, female participants (N=120) completed an eye-tracking task to assess AB to chocolate pictures in which the expectancy of receiving chocolate was manipulated on a trial-by-trial basis (0%, 50%, 100%). Participants were randomly allocated such that half completed the task when hungry (hungry condition), and half completed the task following a lunch meal (satiated condition). Participants also indicated the extent to which they perceived themselves to be 'food addicts' (SPFAs: *n*=37; Non-addicts: *n*=53; Undecided: *n*=28). Consistent with previous findings, there was a significant main effect of chocolate expectancy; food-related AB was greater on 100% and 50% trials, compared to 0% trials. However, there was no effect of hunger condition (hungry vs. satiated) on AB. Contrary to our hypotheses, SPFAs did not show increased AB to food-cues, and this was not moderated by hunger condition or the expectancy information. Exploratory analyses revealed that higher desire-to-eat (DtE) chocolate was associated with increased AB to chocolate pictures. These findings partially support contemporary theoretical models of AB by indicating a key role for state factors (reward expectancy, DtE) in determining AB to food-cues, while a trait factor (SPFA) was not a significant determinant of food AB.

Key words: Food addiction; Expectancy; Attentional bias; Hunger; Desire-to-eat
Abbreviations: AB, Attentional bias; DtE, desire-to-eat; SPFA, self-perceived food addict/self-perceived food addiction

Introduction

Evidence suggests that individuals who are prone to overeating, such as those with obesity, may have similar neuronal adaptations to those who engage in frequent substance-use (Berridge, Ho, Richard, DiFeliceantonio, 2010). This has prompted the suggestion that neurocognitive models of addiction may be useful for understanding the mechanisms which facilitate overeating (Berridge et al., 2010; Nijs & Franken, 2012). One particularly popular model is Incentive Sensitization Theory (IST) (Berridge & Robinson, 1998; Robinson & Berridge, 1993; Robinson & Berridge, 2008). According to IST, the repeated consumption of a drug sensitizes the release of dopamine within brain 'reward' pathways in response to drug-related cues. This occurs through a process of classical conditioning, whereby cues which have repeatedly been associated with the availability of drugs (e.g. visual or orosensory stimuli) acquire incentive salience. These core tenets have been incorporated within models of overeating. For example, a recent 'temptation magnet' model proposes that the presence of palatable foods may capture attention and elicit diet lapses in those with obesity (Appelhans, French, Pagoto, & Sherwood, 2016).

The degree to which an individual demonstrates 'attentional bias' (AB) to food-related cues is therefore thought to provide a proxy measure of a food's incentive value. Indeed, food-related AB has been found to differ as a function of *trait* factors (e.g. weight status, eating behaviours) and *state* factors (e.g. perceived availability, hunger) (e.g. Castellanos et al., 2009; Frayn, Sears, & von Ranson, 2016). However, in a review of the literature, Field et al. (2016) concluded that the influence of trait factors on food-related AB may have been overstated, and that state factors, such as hunger and the perceived availability (expectancy) of a food, may be more important in determining AB to food-cues. In the current study, we therefore examined the influence of trait (i.e. addiction-like eating) and state (i.e. hunger and expectancy) factors on food-related AB.

Trait determinants of attentional bias: Addiction-like eating behaviour

Addiction-like eating behaviour is characterized by an increased appetitive drive for food, and a diminished ability to control these urges (Ruddock, Dickson, Field, & Hardman, 2015; Ruddock, Field, & Hardman, 2017; Ruddock, Christiansen, Halford, & Hardman, 2017). According to the ‘temptation magnet’ theory of obesity (Appelhans, French, Pagoto, & Sherwood, 2016), AB to food-cues should be particularly pronounced in people with addiction-like patterns of eating. The Yale Food Addiction Scale (YFAS; Gearhardt et al., 2009) quantifies and diagnoses ‘food addiction’ based upon DSM criteria for substance-dependence. Using this measure, women with increased food addiction symptomology have been found to demonstrate faster reaction times to food pictures, and this was thought to indicate enhanced attentional processing towards food items (Meule, Lutz, Vögele, & Kübler, 2012). Similarly, in an eye-tracking paradigm, Frayn, Sears, and von Ranson (2016) demonstrated increased attention to unhealthy food pictures (relative to healthy food and non-food images) in those who met the YFAS diagnostic criterion for food addiction, compared to those who did not meet this criterion. However, the validity of applying the DSM substance dependence criteria to eating, as in the YFAS, is heavily debated (Hebebrand et al., 2014; Rogers, 2017; Ziauddeen et al., 2012). In particular, Ziauddeen et al. (2012) suggest that some of the diagnostic symptoms of substance dependence, such as ‘giving up important activities’, have limited applicability to eating behaviour. Furthermore, they suggest that, while some symptoms can be applied to eating (e.g. eating more than intended), the point at which these behaviours become clinically meaningful are yet to be established.

Despite the controversy surrounding the food addiction concept, surveys have revealed that between 27 and 42 percent of community samples believe that they are addicted to food (Hardman et al., 2015; Ruddock et al., 2015). However, as the majority of individuals with ‘self-perceived food addiction’ (SPFA) do not meet the YFAS criteria for food addiction (Ruddock et al., 2017), they remain an understudied population. Nonetheless, research into the cognitive and behavioural characteristics of SPFA is important because people’s beliefs about overeating have been found to affect food intake and body weight (Ruddock et al., 2017; McFerran & Mukhopadhyay, 2013).

Previous research has identified people with SPFA using a single item in which participants are asked to indicate whether or not they perceive themselves to be addicted to food (Meadows, Nolan, & Higgs, 2017; Ruddock et al., 2015). Those who answer positively on such items (i.e. SPFAs) have been found to have increased problematic eating, lower self-control around food, and are more likely to report a ‘preoccupation’ with food and eating, compared with self-perceived ‘non-addicts’ (Meadows, Nolan, & Higgs, 2017; Ruddock et al., 2015). These findings have been corroborated within a laboratory context, in which

SPFAs demonstrated increased food reward (assessed using a measure of 'desire-to-eat') and consumed more calories during an *ad libitum* 'taste test', compared to self-perceived non-addicts (Ruddock et al., 2017). Research into SPFAs therefore has important implications for the identification and treatment of individuals who may be particularly prone to overeating.

State determinants of attentional bias: Hunger and expectancy

Food-related AB also varies as a function of motivational state. Specifically, AB to food tends to be greater in hungry participants, compared to satiated participants (Channon & Hayward, 1990; Lavy & van den Hout, 1993; Mogg, Bradley, Hyare, & Lee, 1998; Placanica, Faunce, & Soames Job, 2001; Stockburger, Hamm, Weike, & Schupp, 2008; Stockburger, Schmalzle, Flaisch, Bublatzky, & Schupp, 2009). Furthermore, using eye-tracking procedures, studies have documented increased AB to chocolate and alcohol pictures (compared to neutral pictures) when chocolate or alcohol was imminently expected (i.e. when participants had 100 percent chance of winning chocolate or alcohol, relative to when they had 50 percent or 0 percent chance) (Field et al. 2011; Jones et al. 2012)[1]. Notably, one study did not find any effect of expectancy on the duration of AB to pizza pictures in hungry participants (Hardman, Scott, Field, & Jones, 2014). In this study, participants were required to refrain from eating lunch prior to testing, and so one explanation is that hunger may have exerted a ceiling effect such that the expectancy information was unable to provoke further increases in food-related AB. The extent to which hunger state might moderate the effect of expectancy on food-related AB therefore merits consideration.

State variations may also interact with between-group *trait* factors to determine the strength of AB to food-cues. For example, Frayn, Sears, and von Ranson (2016) found that a sad-mood induction increased AB to food-cues in people who met the YFAS criteria for 'food addiction', but did not affect AB in those who did not fulfil the YFAS criteria. Furthermore, Castellanos et al. (2009) found that individuals with obesity had greater food-related AB, compared to healthy weight controls, however this trait difference was only found when participants were satiated. In the alcohol literature, Field et al. (2011) reported that trait differences in drinking frequency moderated the effects of expectancy information (i.e. 0%, 50%, 100%) on alcohol-related AB. Specifically, less frequent drinkers

[1] Participants in Field et al. (2011) received alcohol following each 'win' trial. However, the effect of expectancy on attentional bias was still observed when participants received chocolate and alcohol 'points' (rather than *actual* chocolate/alcohol) which they were led to believe would be exchanged for chocolate/alcohol later in the experiment (Jones et al., 2012).

demonstrated increased AB to alcohol pictures when alcohol was imminently expected (i.e. on 100% trials) relative to 50% and 0% trials, while AB in heavy drinkers was insensitive to the expectancy information. These findings (i.e. Castellanos et al., 2009; Field et al., 2011) may be attributable to ceiling effects, whereby hunger and lifetime heavy drinking predicted higher AB *per se* and thus masked any effect of obesity and expectancy, respectively, on AB to reward-related cues.

Research is yet to examine how hunger and expectancy interact with trait influences of self-perceived food addiction (SPFA) to differentially affect AB to food-cues. Based upon previous research (e.g. Castellanos et al., 2009), the presence of hunger may obscure differences in food-related AB between SPFAs and non-addicts. Thus differences in food-related AB between SPFAs and non-addicts may be most pronounced in satiated, relative to hungry, participants. SPFA may also moderate the effect of expectancy on AB to food-cues. However, it is unclear whether the effect of expectancy on AB would be increased or decreased in SPFAs relative to non-addicts. From one perspective, SPFAs may have more automated responses to food-related cues and therefore be *less* responsive to expectancy information (consistent with Field et al., 2011). Alternatively, the effect of expectancy on food-related AB may be *more* pronounced in SPFAs, relative to non-addicts, due to an *increased* motivation to obtain food.

Study aims

The primary aims of the current study were to examine whether people with SPFA would demonstrate increased food-related AB to food-cues, relative to self-perceived non-addicts. Furthermore, we examined whether SPFA would interact with state effects of hunger and expectancy to differentially affect AB. To investigate this, participants completed an eye-tracking task when they were hungry (hungry condition) or following the consumption of a lunch meal (satiated condition). During the task, participants' expectations of receiving chocolate were manipulated prior to each trial, consistent with methods used in previous studies (Field et al., 2011; Hardman et al., 2014; Jones et al., 2012). The following three hypotheses were tested: 1) AB to chocolate pictures (vs. neutral pictures) would be greater for SPFAs compared to non-addicts; 2) The effect of SPFA on AB to chocolate pictures would be most pronounced in the satiated condition, relative to the hungry condition; 3) The effect of the expectancy information on AB would either be increased or decreased in people with SPFA relative to non-addicts.

Method

Participants

Female participants (*N*=120) were recruited from the University of Liverpool via poster and online advertisements. Based on similar previous research (Field et al., 2011), the study was powered to detect a medium-sized effect (f=.28, α=.05) using a 3(group) x 2(condition) x 3(expectancy) mixed design. We decided to use a female-only sample in order to minimise variability in eating behaviours associated with gender differences (Burton, Smit, & Lightowler, 2007). Participants were informed that the aim of the study was to investigate the relationship between food reward and eating behaviour. Inclusion criteria required that participants were non-smokers, had no food allergies or intolerances, had never been diagnosed with an eating disorder, and were not on any medication known to affect appetite. Vegans, or anyone who would be unwilling to consume milk chocolate and cheese sandwiches, were also excluded. Finally, due to the eye-tracking technique used, glasses wearers were unable to take part. All participants completed a medical history questionnaire prior to testing to ensure that they did not suffer from any food allergies. Participants were asked not to eat or consume any calorie-containing drinks for 3 hours before the study. This is consistent with previous research which has examined food reward following a minimum of three hours fasting (Rogers & Hardman, 2015; Ruddock et al., 2017). Furthermore, levels of ghrelin and GLP-1 (associated with hunger and satiety, respectively) have been found to return close to baseline (i.e. following an overnight fast) 3 hours after ingestion of a 590kcal meal (Gibbons et al., 2013). Upon arrival at the lab, participants were asked to write down what they had last eaten, and when they had eaten; inspection of these responses indicated that all participants had refrained from eating for at least 3 hours. Ethical approval was granted by the Institute of Psychology, Health and Society at the University of Liverpool. Participants received course credits or were reimbursed with a £5 shopping voucher as compensation for their time and travel expenses.

Measures and Materials

Appetitive ratings

Levels of hunger, fullness, and desire-to-eat (DtE) chocolate were assessed using 100mm Visual Analogue Scales (VAS). Each scale was anchored by ‘Not at all’ on the left and ‘Extremely’ on the right.

Lunch meal

To induce satiety, participants in the satiated condition were provided with cheese sandwiches. Sandwiches were made using 3 slices of Lidl Simply medium sliced white bread (255kcals, 3g fat), 1.5 pieces of Tesco medium pre-sliced cheddar (56g, 236kcals, 20g fat), and 15g butter (Tesco Butterpak, 95kcals, 11g fat). These were then sliced into six small sandwiches. Participants were left alone for 10 minutes during which they were asked to consume the entire meal. All participants adhered to this instruction.

Self-perceived food addiction

To assess SPFA, participants indicated the extent to which they agreed with the statement "I believe myself to be a food addict". Responses were provided on a 5-point Likert scale which ranged from 'Strongly disagree' to 'Strongly agree'. Similar measures have been used and validated in previous research to assess participants' perceptions of themselves as having a food addiction (Meadows, Nolan, & Higgs, 2017; Ruddock et al., 2015; Ruddock, Christiansen, Jones, et al., 2016; Ruddock, Field, & Hardman, 2017; Ruddock et al., 2017). We previously found that providing a brief description of 'food addiction' did not affect people's qualitative beliefs about 'food addiction', nor did it influence the likelihood of an individual identifying as a food addict (Ruddock et al., 2015). Furthermore, there is yet to be any agreed-upon scientific definition of food addiction. For these reasons, we decided not provide participants with a description of food addiction prior to assessing SPFA.

Attentional bias task

Pictorial stimuli. All stimuli were presented using Inquisit (2.0) on a 15" computer screen. The pictorial stimuli used in the expectancy task consisted of 10 pairs of photographs. These photographs have been used in previous research examining AB to food-cues (Jones et al., 2012). Each pair contained one chocolate-related photograph and one matching control photograph (i.e. stationery items). Picture pairs were matched as closely as possible for colour, complexity, brightness, shape, and size. Each picture was 100mm high and 125mm wide. Four additional picture pairs depicting stationery items were used for the practice trials.

Expectancy task. The task was similar to that used in previous research (Field et al., 2011; Jones et al., 2012; Hardman et al. 2014). Participants were led to believe that they were playing for 'points' which, following the task, would be exchanged for chocolate. As in previous research (Hardman et al., 2014; Jones et al., 2012), participants were awarded chocolate 'points', rather than actual chocolate pieces, due to concerns that consuming chocolate during the eye-tracking task may diminish the motivational value of chocolate (due to satiety). Prior to each trial, the expectancy of 'winning' a point was manipulated. Specifically, participants were instructed to pay attention to a percentage (100%, 50%, or 0%) that was presented in the center of the screen for 1000 milliseconds at the start of the trial. Participants were explicitly told that this percentage represented the probability that they would 'win' a point on that particular trial. The percentage was then followed by the presentation of a picture pair (i.e. chocolate image and control image) for 2000 milliseconds during which eye movements were recorded. Following picture offset, the instruction 'press SPACE BAR to try and win!' was presented in the center of the screen. Pressing the space bar triggered the feedback screen in which participants were informed whether or not they had 'won' a point. On all 100% trials, and half of the 50% trials, the feedback stated "You win a chocolate point". On all 0% trials, and half of the 50% trials, the feedback stated "You win nothing". The feedback screen was displayed for 1000 milliseconds. The order and duration of each screen presentation is shown in Figure 1. Four practice trials were presented prior to the start of the task (one 100% trial, one 0% trial, and two 50% trials). The main block consisted of 120 trials. Each trial type (i.e. 100%, 50%, or 0%) was presented 40 times. The positioning of chocolate pictures was such that they appeared on the left and right side of the screen with equal frequency for each trial type. Participants were seated approximately 23 inches away from the computer screen with their chin on a chin-rest. Eye movements were recorded using an Eye-Trac D6 desktop mounted camera (Applied Science Laboratories, Bedford, MA). The task lasted approximately 15 minutes

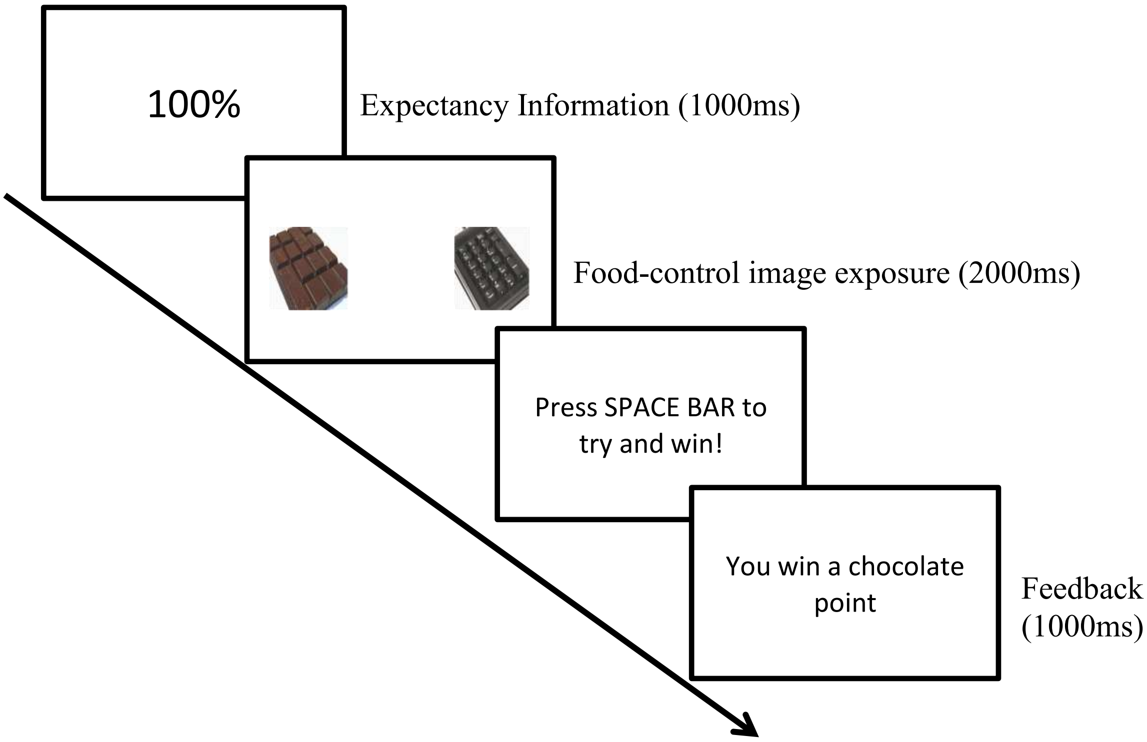

Figure 1. Order and duration of screen presentation in the eye-tracking task during a single 100% trial. The task consisted of 120 trials and each trial type (i.e. 100%, 50%, 0%) was presented 40 times.

Additional measures and eating trait questionnaires.

The Yale Food Addiction Scale (YFAS; Gearhardt et al., 2009), Three Factor Eating Questionnaire (TFEQ, Stunkard & Messick, 1985), and Binge Eating Scale (BES; Gormally, Black, Daston, & Rardin, 1982) were used to provide descriptive information about the sample.

The YFAS (Gearhardt et al., 2009) consists of 25 items designed to measure an addiction to foods high in fat and/or sugar. The scale is based on the DSM-IV criteria for substance dependence. A diagnosis of food addiction is given when the individual demonstrates significant clinical impairment due to their eating behaviours, and fulfils at least three of the following symptoms: unsuccessful attempts to quit, giving up activities to eat, eating large portions, continuing to overeat despite negative consequences, tolerance to food, withdrawal from not eating, and spending a lot of time eating. The YFAS also provides a continuous measure of the number of food addiction symptoms exhibited by an individual (i.e. symptom count) which range from 0 to 7.

The BES (Gormally, Black, Daston, & Rardin, 1982) consists of 16 items which assess the severity of binge eating symptoms. Higher scores on the BES indicate more severe binge eating symptoms.

Participants completed the ‘Restraint’ (TFEQ-R) and ‘Disinhibition’ (TFEQ-D) sub-scales of the TFEQ (Stunkard & Messick, 1985). Dietary restraint refers to attempts to restrict food intake, while disinhibition refers to the general tendency to overeat.

Familiarity ratings.

Participants were asked to indicate how often they ate chocolate. The following response options were given: ‘Never’, ‘Monthly or less’, ‘2-4 times a month’, ‘2-3 times a week’, ‘4 or more times a week’, ‘Every day’. Participants indicated how often they ate each food by ticking the appropriate box.

Procedure

All sessions were conducted between 12pm and 6pm and took approximately 1 hour to complete. Prior to each session, participants were randomly allocated (using the randomisation generator at www.randomlists.com) to either hungry or satiated conditions. Upon arrival, participants provided written informed consent and completed a medical history questionnaire to ensure the absence of any food allergies. To ensure compliance with the study procedure, participants were asked to confirm that they had not eaten for at least 3 hours prior to the study. Participants indicated their current levels of hunger, fullness, and DtE chocolate. Those in the satiated condition then ate the cheese sandwiches, while those in the hungry condition read a magazine for 10 minutes. Levels of hunger, fullness, and DtE chocolate were then reassessed. Participants then completed the eye-tracking task in which they were led to believe that they were playing for ‘chocolate points’. Levels of hunger, fullness, and DtE chocolate were assessed again after completing the eye-tracking task. Participants were then given a bowl containing 100g of chocolate (Galaxy Counters: 528 kcal, 28.9g fat) under the pretence that this was what they had ‘won’ during the task. Participants were invited to consume as much as they wished. Chocolate intake was measured by covertly weighing the bowl before and after consumption. Following this, participants’ levels of hunger, fullness, and DtE chocolate were assessed again, and participants completed the chocolate familiarity scale. To assess demand characteristics, participants were asked to indicate what they thought the aims of the study were. Finally, participants completed the measure of SPFA, TFEQ, YFAS, and BES, and measures of height and weight were taken to calculate BMI. Participants were fully debriefed and thanked for their time.

Data analysis

Self-perceived food addiction

Prior to data analysis, SPFAs and non-addicts were identified based on participants' responses to the assessment of SPFA. Those who ticked 'Agree' or 'Strongly agree' to the assessment of SPFA were grouped as SPFAs, while those who ticked 'Disagree' or 'Strongly disagree' were grouped as 'Non-addicts'. Those who indicated that they 'Neither agree nor disagree' were classed as 'Undecided'. A chi-square analysis was conducted to ensure that the number of SPFAs, Non-addicts and Undecided participants were evenly distributed across hungry and satiated conditions.

Appetite ratings

Mixed design ANOVAs were conducted to confirm that the lunch meal successfully reduced appetite in the satiated, relative to hungry, condition. DtE, hunger, and fullness at time-points 1 (T1; i.e. upon arrival to the lab), time-point 2 (T2; i.e. following consumption of the sandwich or after 10 minutes of reading), time-point 3 (T3; i.e. following the AB task), and time-point 4 (T4; i.e. following *ad libitum* chocolate intake), were entered as repeated measures. Condition (i.e. hungry/satiated) was entered as a between-subjects variable. As SPFA may have moderated the effect of condition (i.e. hungry/satiated) on appetite ratings, this was included in the ANOVA as a between-subjects factor. Each ANOVA therefore comprised a 2 (condition: hungry/satiated) x 3 (group: SPFA/Non-addicts/Undecided) x 4 (time-point: T1/T2/T3/T4) design. Where significant condition x time interactions were observed, these were followed up using paired-samples t-tests conducted within each condition. Specifically, differences in appetite ratings between time-points 1 and 2 (i.e. before and after the lunch meal/10-minutes reading) were examined to ensure that the lunch meal (in the satiated condition) had the desired effect of reducing appetite.

Attentional bias

For each participant, mean gaze duration (i.e. the amount of time spent looking at each picture) to chocolate and neutral pictures was calculated for each trial type (i.e. 0%, 50%, 100%). To check for the presence of AB to chocolate pictures, gaze duration was analysed using a 3 (expectancy: 100%, 50%, 0%) x 2 (picture type: chocolate/neutral) repeated measures ANOVA. AB scores were then calculated by subtracting gaze duration to neutral pictures from gaze duration to chocolate pictures. A positive score indicated AB towards the chocolate pictures, while a negative score indicated AB towards the neutral pictures.

In order to test the study hypotheses, the effects of expectancy, condition, and group on AB scores were explored using a 3 (expectancy: 100%, 50%, 0%) x 2 (condition: Hungry/Satiated) x 3 (group: SPFAs/Non-addicts/Undecided) mixed ANOVA. Hypothesis 1 predicted a main effect of group, such that AB to chocolate pictures (vs. neutral pictures) would be higher in SPFAs compared to non-addicts. Hypothesis 2 predicted a group (SPFA vs. non-addicts) x condition (hungry vs. satiated) interaction, such that increased AB to chocolate-pictures, in SPFAs, was expected to be most pronounced in the satiated condition, relative to the hungry condition. Hypothesis 3 predicted a group (SPFA vs. Non-addicts) x expectancy (100%, 50%, 0%) interaction. Specifically, the effect of expectancy on AB to chocolate-pictures was predicted to be either increased or decreased in SPFAs, relative to Non-addicts.

Results

Participant characteristics

Due to technical problems with the eye-tracker, data from two participants were lost. Data analysis was therefore conducted on 118 complete datasets (hungry condition: n=59; satiated condition: n=59). Participant characteristics, stratified by condition (i.e. hungry/satiated) are provided in Table 1. A MANOVA confirmed that participants did not differ, between conditions, with regards to any of these characteristics, $F(9,105)=1.04$, $p=.412$. Furthermore, a chi-squared test showed that the number of people identifying as SPFAs, Non-addicts, and Undecided participants did not differ between hungry and satiated conditions, $X^2(2)=.83$, $p=.659$. All participants indicated that they consumed chocolate at least 2-4 times a month, and there were no between-condition differences with regards to the frequency of chocolate consumption, $X^2(3)=4.65$, $p=.199$.

Participant characteristics stratified by group (i.e. Non-addicts, Undecided, SPFAs) are provided in Table 2. A MANOVA revealed that groups (i.e. Non-addicts, Undecided, SPFAs) differed on several eating behaviour traits, $F(14,218)=3.01$, $p<.001$. Specifically, between-group differences were observed for TFEQ-D (disinhibition subscale) scores, $F(2,114)=14.37$, $p<.001$, BES scores, $F(2,114)=10.80$, $p<.001$, and YFAS symptom count, $F(2,114)=7.10$, $p=.001$ (see Table 2). Post-hoc comparisons revealed that, for each of these variables (i.e. TFEQ-D, BES, and YFAS symptom count), both SPFA and Undecided groups scored significantly higher than the Non-addict group (all $ps<.021$). No significant differences were observed between SPFA and Undecided groups (all *ps* >.05). Of the 37 people who identified as food addicts, 12 (32%) were overweight or obese and 25 (68%) were normal weight or underweight. Of the 53 participants who identified as non-addicts, 15 (28%) were overweight/obese and 38 (72%) were normal- or underweight. Nine participants who were 'undecided' were overweight or had obesity (32%), and 19(68%) were normal/underweight.

Table 1. *Participant characteristics in the hungry and satiated conditions. Unless otherwise stated, values are means ± standard deviations.*

Characteristic	Hungry (*n*=59)	Satiated (*n*=59)	Total (*n*=118)
Age (years)	25.6 ± 8.3	25.0 ± 10.2	25.3 ± 9.2
BMI (kg/m^2)	23.4 ± 5.1	23.9 ± 5.1	23.7 ± 4.9
TFEQ-D	7.5 ± 3.4	7.5 ± 3.1	7.5 ± 3.3
TFEQ-R	9.2 ± 4.9	7.5 ± 4.3	8.3 ± 4.7
BES	10.1 ± 6.6	10.6 ± 7.3	10.4 ± 6.9
YFAS symptom count	1.81 ± 1.38	2.14 ± 2.14	1.97 ± 1.39
Chocolate liking (100-mm VAS)	73 ± 80	80 ± 16	77 ± 19
SPFAs, non-addicts, undecided (*n*)	17,26,16	20,27,12	37,53,28
YFAS diagnosis (*n*)	3	4	7
Choc intake (g)	40.6 ± 24.2	38.3 ± 22.2	39.5 ± 23.1

Table 2. *Participant characteristics stratified by group (Non-addicts, Undecided, SPFAs,). Unless otherwise stated, values are means ± standard deviations.*

Characteristic	Non-addicts (*n*=53)	Undecided (*n*=28)	SPFAs (*n*=37)
Age (years)	26.0 ± 10.2	26.4 ± 9.4	23.5 ± 7.5
BMI (kg/m^2)	23.0 ± 4.4	24.5 ± 5.4	24.0 ± 5.0
TFEQ-D	5.9 ± 3.1*	8.3 ± 2.8	9.2 ± 2.8
TFEQ-R	7.9 ± 4.5	10.0 ± 3.8	7.6 ± 5.3
BES	7.3 ± 6.0*	12.8 ± 6.0	12.9 ± 7.2
YFAS symptom count	1.5 ± 0.9*	2.2 ± 1.4	2.5 ± 1.7
Chocolate liking (100-mm VAS)	74.8 ± 19.5	78.9 ± 16.1	77.5 ± 21.8
YFAS diagnosis (*n*)	2	2	3
Choc intake (g)	35.5 ± 23.1	41.8 ± 21.6	43.4 ± 24.0

*Significant difference between Non-addicts and Undecided/SPFA groups (*p*<.05).

Appetite ratings

Ratings of hunger, fullness, and DtE chocolate over each of the four time-points are depicted in Figure 2. Significant condition x time interactions were observed for DtE, hunger, and fullness ratings (*ps* <.001). Follow-up paired t-tests, conducted between time-points 1 and 2 (i.e. before and after the lunch meal or 10-minutes reading), showed that hunger and

DtE chocolate ratings decreased, and fullness ratings increased significantly in the satiated condition (all *ps* <.001). Hunger, fullness and DtE chocolate ratings did not change in the hungry condition between T1 and T2 (*ps* >.137). This confirms that the lunch meal was effective in reducing appetite and increasing fullness in the satiated condition, in the absence of any changes in the hungry condition. Furthermore, consumption of the lunch meal elicited a large-effect on hunger ratings between T1 and T2 (d=1.86). There was no 3-way interaction of time x condition x group (SPFAs/Non-addicts/Undecided) on any appetite measure (all *ps*>.233).

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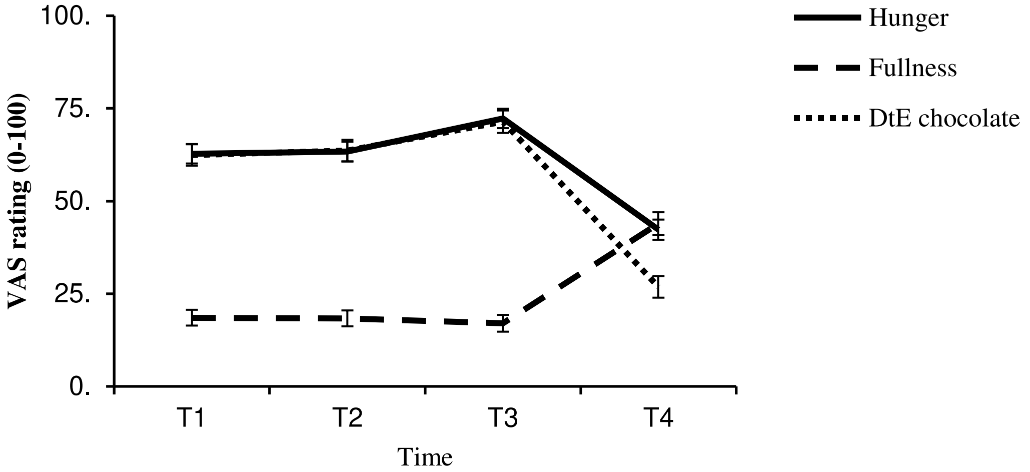

B

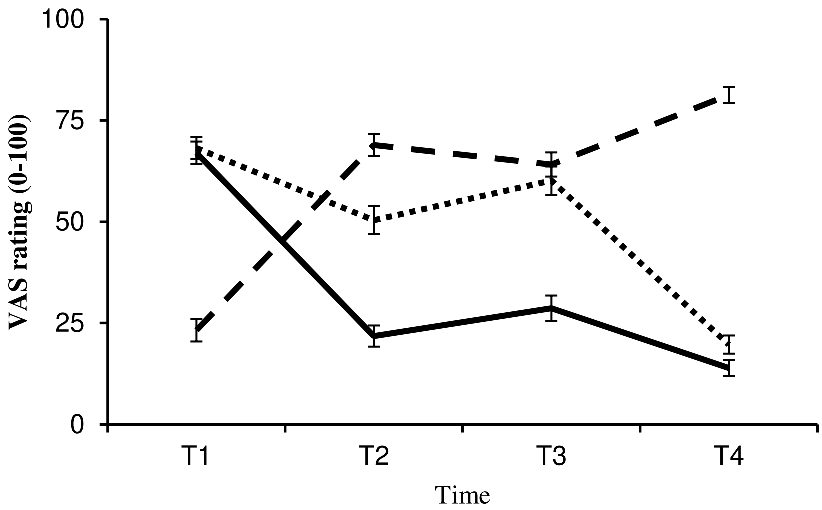

Figure 2. Ratings of hunger, fullness, and DtE chocolate at each time-point for hungry (Panel A) and satiated (Panel B) conditions. T1 (time-point 1): arrival to the lab. T2 (time-point 2): following consumption of the sandwich/10 minutes of reading. T3 (time-point 3): following the AB task. T4 (time-point 4): following *ad libitum* chocolate intake. Values are means and standard errors.

Figure 2 (panel B) shows a greater decline in hunger than DtE chocolate ratings following consumption of the lunch meal. We therefore conducted exploratory analyses to compare the decline in hunger and DtE ratings between T1 and T2 in the satiated condition. Hunger and DtE rating decline was calculated by subtracting ratings obtained at T2, from those obtained at T1. A paired-samples t-test revealed that the decline in hunger ratings (M=45 ± 24) was significantly greater than the decline in DtE ratings (M=18 ± 24), $t(58)=7.79$, $p<.001$.

Attentional bias

Analyses revealed a main effect of picture type, $F(1,117)=75.88$, $p<.001$, $\eta p^2=.39$, such that participants demonstrated increased overall gaze duration towards the chocolate (M=719ms ± 259) compared to neutral pictures (M=490ms ± 191) indicating an AB to chocolate-related cues.

Contrary to Hypothesis 1, there was no main effect of group (i.e. SPFAs, Non-addicts, Undecided) on AB to chocolate-pictures, $F(2,112)=.06$, $p=.945$, $\eta p^2=.00$. There was also no group x condition interaction, $F(2,112)=.51$, $p=.600$, $\eta p^2=.01$ (hypothesis 2), and no group x expectancy interaction, $F(3.53, 197.90)=.88$, $p=.465$, $\eta p^2=.02$ (hypothesis 3).[2]
There was, however, a main effect of expectancy on AB scores, $F(1.77,197.90)=11.01$, $p<.001$, $\eta p^2=.09$ (Figure 3). Pairwise comparisons revealed that participants demonstrated greater AB towards the chocolate pictures when they had 100% (M=255ms ± 328;$p=.001$) or 50% (M=249ms ± 307;$p<.001$) chance of winning, compared to when they had 0% chance (M=182ms ± 287). AB scores did not differ significantly between 100% and 50% trials ($p=.657$). A one-sample T-test revealed that AB to chocolate pictures differed significantly from zero on 0% trials, $t(117)=6.90$, $p<.001$, 50% trials, $t(117)=8.80$, $p<.001$, and 100% trials, $t(117)=8.45$, $p<.001$ There was no main effect of hunger condition, $F(1,112)=.128$, $p=.722$, $\eta p^2=.001$, and no expectancy x condition interaction, $F(1.77,197.90)=1.21$, $p=.297$, $\eta p^2=.011$, on AB scores. There was also no significant 3-way interaction of expectancy x condition x group, $F(4,224)=1.81$, $p=.128$, $\eta p^2=.031$.

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[2] Analyses of AB were repeated using YFAS symptomology (instead of self-perceived food addiction) as a between-subjects factor. For this, participants were grouped into either high (*n*=62) or low (*n*=56) YFAS groups based on a median split of YFAS symptom scores. Those in the high YFAS group met the criteria for 2 or more symptoms, while those in the low YFAS group met the criteria for 0-1 symptoms. The number of participants in each YFAS group was evenly distributed across hungry (low: *n*=31; high: *n*=28) and satiated (low: *n*=25; high: *n*=34) conditions, $X^2(1)=1.22$, $p=.357$. The likelihood of participants identifying as a 'food addict' differed significantly between YFAS symptom groups $X^2(2)=8.76$, $p=.013$. Of the 37 participants who identified as food addicts, 68 percent (*n*=25) were in the high YFAS group. Of the 53 participants who identified as non-addicts, 62 percent (*n*=33) were in the low YFAS group. Grouping based on high/low YFAS symptoms yielded no main effect of group, and no group x condition or group x expectancy interaction, on attentional bias to chocolate-pictures (*ps* > .125).

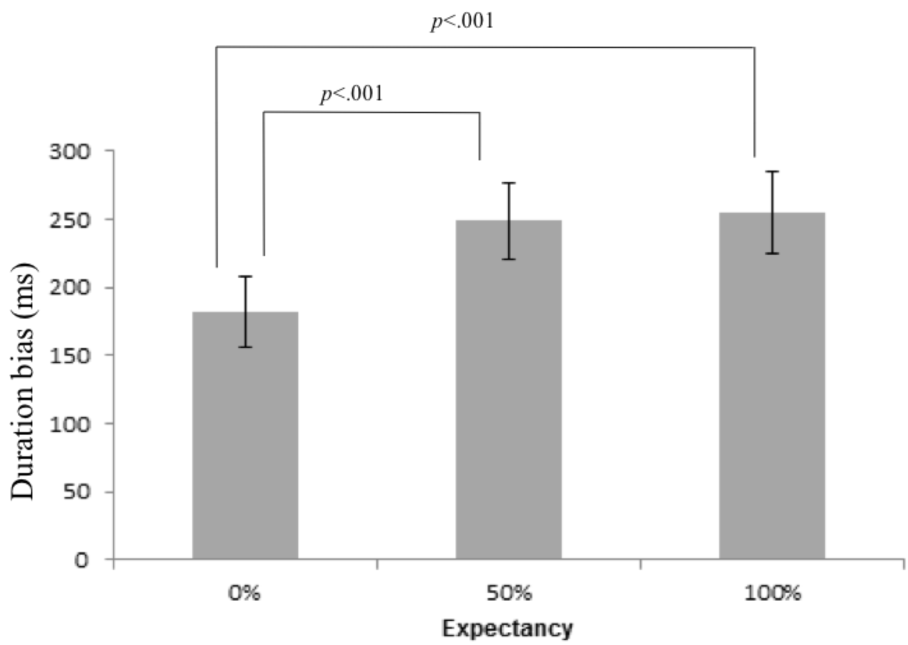

Figure 3. Mean duration bias (in milliseconds) towards chocolate pictures as a function of perceived probability of receiving a chocolate point. Values are mean ± SEM.

Exploratory analyses: Desire-to-eat

Exploratory correlational analyses were conducted to investigate relationships between the dependent variables (see Table 3). Given its non-parametric properties, correlates of SPFA (i.e. Strongly disagree=1; Strongly agree=5) were examined using Spearman's rho. To ensure the absence of Type 1 errors associated with multiple comparisons, we selected a conservative alpha level of $p<.001$. There was a significant positive correlation between DtE chocolate and AB on 50% and 100% trials, but not on 0% trials. DtE chocolate ratings also correlated positively with hunger and chocolate intake.

Table 3. *Correlation coefficients between dependent variables. Values were collapsed across conditions (hungry and satiated). Hunger and DtE chocolate ratings were taken at T2 (i.e. just prior to the eye-tracking task) **p<.001, *p<.05*

	Expectancy	Hunger	DtE	SPFA	YFAS symptom count	Chocolate intake	BMI	TFEQ-R	TFEQ-D	BES
Attentional bias	0%	.132	.145	r_s =.015	.047	.000	-.153	.023	-.055	.010
	50%	.082	.237**	r_s =-.010	.125	.040	-.228*	.081	.007	.072
	100%	.044	.249**	r_s = .026	.170	.042	-.152	.024	-.021	.064
Hunger			.501**	r_s = .082	-.035	.226*	-.152	.087	.041	.068
DtE				r_s = .181	.031	.365**	-.063	-.057	.110	.041
SPFA					r_s =.301**	r_s =.175	r_s= .100	r_s= -.037	r_s=.505**	r_s=.407**
YFAS symptom count						.092	.071	.132	.373**	.598**
Chocolate intake							.017	-.156	.153	.026
BMI								.136	.239**	.172
TFEQ-R									.256**	.262**
TFEQ-D										.643**

As shown in Table 3, DtE chocolate ratings correlated positively with AB to chocolate pictures on 50% and 100% trials but not 0% trials. We therefore conducted an ANCOVA to examine the effect of expectancy on AB after controlling for DtE chocolate ratings at T2 (i.e. prior to the eye-tracking task). Expectancy was entered as a within-subject variable, and DtE was entered as a covariate. There was an expectancy x DtE interaction which approached significance, $F(1.77, 205.24)=2.62$, $p=.082$, $\eta p^2=.02$, and the main effect of expectancy on AB was no longer significant, $F(1.77,205.24)=.079$, $p=.904$, $\eta p^2=.00$.

To further investigate the role of DtE, participants were divided into either ‘high DtE’ ($n=60$) or ‘low DtE’ ($n=58$) groups based on a median split of DtE ratings at T2 (i.e. just prior to the eye-tracking task). The mean (± SD) DtE VAS rating was 77mm (± 11) and 37mm (± 19) for the high and low DtE groups, respectively. This was entered into a 3 (expectancy) x 2 (DtE chocolate) mixed ANOVA with AB scores as the dependent variable. There was a main effect of DtE chocolate, $F(1,114)=5.55$, $p=.020$, $\eta p^2=.05$, such that those in the high DtE group demonstrated greater AB towards the chocolate (M=288ms ± 275) than those in the low DtE group (M=166ms ± 275). There was also an interaction between DtE and expectancy, $F(1.79, 203.96)=5.54$, $p=.006$, $\eta p^2=.05$ (see Figure 4). Paired samples t-tests, conducted separately for low and high DtE groups revealed that, for those in the low DtE group, AB did not differ between 0%, 50%, or 100% trials (all $ps > .341$). However, for those with high DtE, AB was significantly higher on 50% trials, $t(59)-4.02$, $p<.001$, $d=.37$, and 100% trials, $t(59)=-4.11$, $p<.001$, $d=.42$, compared to 0% trials. AB did not differ between 50% and 100% trials in the high DtE group, $t(59)=-.90$, $p=.373$.

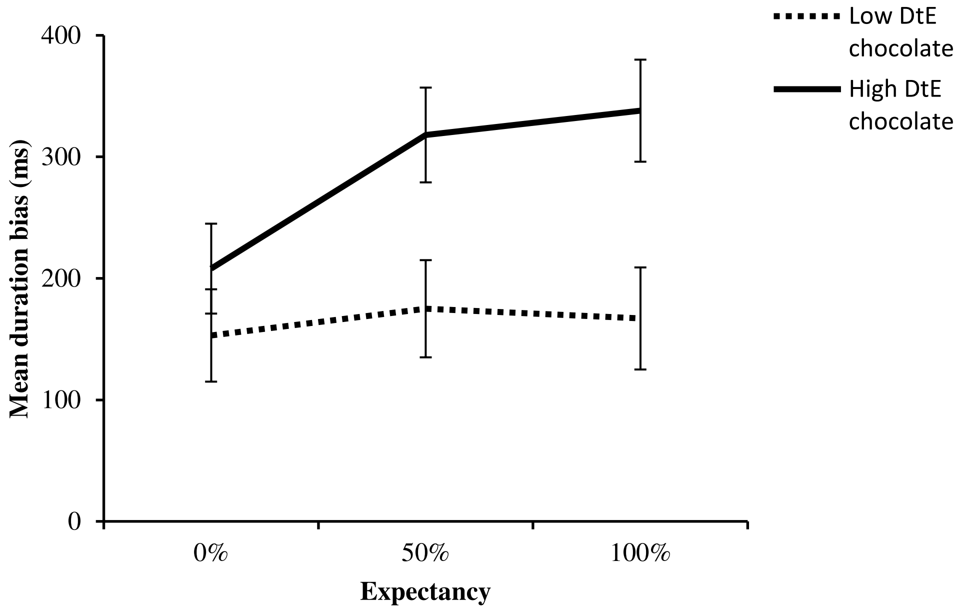

Figure 4. Mean duration bias as a function of expectancy information and DtE chocolate

Predictors of chocolate intake

An exploratory multiple linear regression analysis was conducted to examine the extent to which *ad libitum* chocolate intake could be predicted from appetitive measures (i.e. hunger, fullness, and DtE), YFAS symptom count, and AB. Hunger, fullness, and DtE ratings from time-point 3 (T3; i.e. just prior to *ad libitum* chocolate intake) were included in the model. To examine the predictive ability of SPFA, groups (Non-addicts, Undecided, SPFAs) were dummy coded and entered into the model with Non-addicts as the reference category. AB scores were collapsed across all 3 trial types (i.e. 0%, 50%, 100%) to provide an overall AB score[3]. DtE ratings were the only significant predictor of subsequent chocolate intake (Table 4).

[3] We conducted a separate regression model to examine whether chocolate intake could be predicted by attentional bias at each level of expectancy (0%,50%, 100%). No significant effects were found (all *ps* >.576).

Table 4. *Output from linear regression model of variables predicting chocolate intake (g). Values for hunger, fullness, and DtE were taken at T3 (i.e. just prior to ad libitum intake). *Significant at p<.01.*

	β	p	95% confidence intervals	SR^2
Hunger	.24	.243	-.12, .47	.01
Fullness	.11	.612	-.23, .40	.00
DtE	.32*	.004	.10, .48	.07
SPFAs vs. non-addicts	.09	.367	-5.40, 14.47	.01
Undecided FA vs. non-addicts	.09	.343	-5.43, 15.50	.00
YFAS symptomology	.05	.631	-2.37, 3.89	.00
Attentional bias	-.03	.737	-16.85, 11.96	.00
Condition (hungry vs. satiated)	.10	.475	-8.35, 17.80	.00

SR^2 = Squared semi-partial correlation (proportion of variance in chocolate intake that is uniquely accounted for by each variable).

Discussion

Contrary to our hypotheses, results revealed no main effect of group (i.e. SPFAs, Non-addicts, Undecided) on AB to chocolate-pictures. This was despite the fact that SPFAs scored significantly higher than Non-addicts on measures of over-eating (i.e. TFEQ-D, BES, and YFAS symptom count), and these constructs have previously been associated with greater AB to food-cues (Deluchi, Costa, Friedman, Gonçalves, & Bizarro, 2017; Frayn, Sears, von Ranson 2016; Hardman et al., 2013; Seage & Lee, 2017). Neither condition (hungry vs. satiated), nor the expectancy manipulation, moderated the effect of SPFA on AB. There was also no overall difference between the hungry and satiated conditions on AB and this could partly explain the lack of effect of SPFA. This is because SPFAs were expected to have higher levels of AB than non-addicts in the *satiated* condition, but not the hungry condition, so the lack of between-condition differences in AB as a function of hunger state may have obscured this effect.

Nonetheless, consistent with previous findings (Field et al., 2011; Hardman et al., 2014; Jones et al., 2012), participants demonstrated greater AB towards chocolate pictures when they were led to believe they had 100% chance of receiving chocolate compared to when they had 0% chance. These findings lend further support to the suggestion that AB is enhanced towards stimuli that predict imminent receipt of a reward (Field & Cox, 2008). It is also important to note that, compared to 0% trials, AB increased when the chances of receiving chocolate were uncertain (i.e. 50% trials). These findings differ from previous research in which AB to alcohol pictures did not differ significantly between 0% and 50% trials (Field et al., 2011). While these findings are *partly* consistent with the suggestion that increased AB should be observed in situations in which the outcome is uncertain (Pearce & Hall, 1980), this was not fully supported by the current findings as AB was greater on 100% trials, compared to 50% trials, albeit not significantly. Similar linear relationships between expectancy and early AB to food, and cravings for cigarettes, have previously been observed (Carter & Tiffany, 2001; Hardman et al., 2014).

Contrary to previous findings (Channon & Hayward, 1990; Lavy & van den Hout, 1993; Mogg, Bradley, Hyare, & Lee, 1998; Placanica, Faunce, & Soames Job, 2001; Stockburger, Hamm, Weike, & Schupp, 2008; Stockburger, Schmalzle, Flaisch, Bublatzky, & Schupp, 2009), participants in the hungry condition did not demonstrate any increased AB towards chocolate pictures compared to those in the satiated condition. This is inconsistent with theoretical models of AB which posit a key role of state factors, such as hunger, in determining food-related AB (Field et al., 2016). There are several possible explanations for these findings. Firstly, the between-subjects design used to manipulate hunger/satiety in the current study may have masked effects on attentional bias – that is, the effect of state differences on AB may be most pronounced when assessed within the same subject. However, contrary to this, a recent study reported no within-subject change in attention to dessert pictures following ad libitum consumption of a sandwich lunch to induce satiety (Davidson, Giesbrecht, Thomas, & Kirkham, 2018). A second possibility is that the instruction to refrain from eating for 3-hours prior to the study may not have induced adequate levels of hunger. Equally, the lunch meal provided in the satiated condition may not have sufficiently reduced levels of hunger. Contrary to these possibilities, however, mean ratings of hunger were similar to those observed in studies in which participants were required to fast overnight (Gibbons et al., 2013). Furthermore, consumption of the lunch meal elicited a large-effect (d=1.86) on hunger ratings between T1 (i.e. upon arrival at the lab) and T2 (i.e. following the lunch meal).

Therefore, a more likely possibility is that the lunch meal did not sufficiently reduce the reward value of chocolate. Indeed, previous research has demonstrated a role for sensory specific satiety in influencing the attention to food. Specifically, di Pellegrino, Magarelli, & Mengarelli (2011) reported diminished AB towards an *eaten* food, but not towards an *uneaten* food. Similarly, Davidson et al. (2018) reported decreased attention to sandwich pictures following an *ad libitum* sandwich lunch, while attention to dessert pictures remained unchanged. In further support of this suggestion, exploratory analyses in the current study found that DtE chocolate ratings did not diminish to the same extent as general (i.e. non-food specific) hunger ratings following consumption of the cheese sandwich which had different sensory properties. This suggests that chocolate may have continued to function as an effective reinforcer despite recent eating.

In relation to the above point, further exploratory analyses suggested that DtE chocolate played a key role in determining AB to chocolate pictures. Firstly, participants with higher levels of DtE chocolate demonstrated greater overall AB towards chocolate pictures than participants with lower levels of DtE. This is consistent with previous research which found a positive correlation between AB for substance-related cues and substance craving (Field et al., 2009). Secondly, a DtE by expectancy interaction was observed such that only participants with high momentary levels of DtE chocolate demonstrated sensitivity to the expectancy information. This extends Field & Cox's (2008) model of AB by suggesting that the imminent availability of a reward may increase AB, but only for individuals with a pre-existing 'desire' for the reward. Future research should examine whether this interaction is mediated by the extent to which individuals attend to expectancy information. Specifically, relative to those with low-levels of DtE, those with higher DtE may pay more attention to, and thus be more affected by, information about the availability of the desired food.

Due to the exploratory nature of these findings, future research is required to replicate the effect of DtE on food-related AB. Furthermore, as DtE was not experimentally manipulated, we are unable to speculate upon the direction of the relationship between DtE and AB. Specifically, it is unclear whether DtE was *directly* associated with increased AB to food-cues, or whether the relationship was facilitated by the underlying incentive value of the chocolate, consistent with Field et al.'s (2016) suggestion.

Findings from the current study also contribute to a body of research examining the extent to which AB predicts subsequent food intake. Contrary to previous findings (Nijs, Franken, & Muris, 2010; Werthmann, Renner, Roefs, et al., 2014; Werthmann, Roefs, Nederkoorn, & Jansen, 2013), there was no positive association between AB to chocolate pictures (at any level of expectancy, or collapsed across all three levels) and chocolate consumption. Rather, DtE ratings provided the only significant predictor of chocolate intake.

These findings are consistent with Hardman et al. (2014) in which DtE ratings, and not AB, positively predicted pizza consumption. Future research should explore the extent to which DtE ratings, which are thought to provide a subjective measure of a food's reward value (Rogers & Hardman, 2015), underlie positive relationships between AB and subsequent intake.

Taken together, findings from the current study provide insight into the mechanisms which underlie attentional bias to food-cues. Firstly, consistent with Field et al. (2016), they suggest that *state* factors, such as DtE, exert greater influence than *trait* differences (i.e. SPFA, disinhibited eating) on food-related AB. Secondly, results suggest that attentional bias represents a cognitive output of a motivational process and is therefore only *indirectly* related to behaviour (Field et al., 2016). This has important implications for attentional bias modification (ABM) techniques which attempt to alter behaviour by instructing participants to 'attend to' or 'avoid' certain cues (e.g. food pictures). Specifically, our findings support the idea that ABM may target a cognitive marker of a motivational process (Field et al., 2016).

The current study yields a number of limitations which should be considered in future research. Firstly, the use of a single food-cue (i.e. chocolate pictures) for the assessment of AB may have precluded the observation of individual differences between SPFAs and Non-addicts. The use of chocolate cues was based on previous research which suggest that chocolate is perceived to be a particularly 'addictive' food (i.e. Ruddock et al., 2015, Schulte, Avena, & Gearhardt, 2015). However, evidence suggests that individuals' 'problem' foods are highly idiosyncratic (e.g. Schulte, Avena, & Gearhardt, 2015), and therefore the stimuli used in the current study may not have been sufficient to capture differences in AB to food-cues in SPFAs and Non-addicts. Future research may therefore benefit from using personalised food stimuli to assess trait differences in AB to food-cues. Secondly, due to between-gender differences in eating behaviours (Burton, Smit, & Lightowler, 2007) the current study used an all-female sample. It is therefore not possible to generalize our findings to a male population. Nonetheless, as this was a preliminary study, it was necessary to minimize between-subject variability. Future research is now required to explore state and trait influences on AB to food-cues within a male sample. It is also important to consider that the study design could be strengthened by randomising participants equally to hungry/satiated conditions on the basis of self-perceived food addiction. However, this would require assessing SPFA prior to the start of the study, which would raise concerns over demand characteristics. Importantly, numbers of self-perceived food addicts did not differ significantly between the two conditions. Finally, the lack of difference in attentional bias between participants with and without SPFA may be due to the fact that both groups had similar levels of dietary restraint (as assessed using the TFEQ-R). However, consistent with previous research (Werthmann et al., 2013), we found no significant relationship between TFEQ-R scores and attentional bias, suggesting that this is unlikely to have affected our findings. Nonetheless, it is important for future research, examining trait and state differences in food-related attentional bias, to assess participants' dieting status. Previous research has found that highly restrained current dieters had lower food-related cognitive bias, relative to highly restrained *non*-dieters (Tapper, Pothos, Fadardi, & Ziori, 2008). It is therefore possible that participants' dieting status, which was not accounted for in the current study, may have affected our overall findings. Furthermore, SPFA may have been affected by social desirability, such that some participants may have been reluctant to label themselves a 'food addict'. Nonetheless, the validity of our measure of SPFA is supported by the fact that SPFAs scored higher than non-addicts on measures of disinhibited eating (i.e. TFEQ-D, YFAS symptoms, BES).

It is also important to consider the possibility that individuals who fulfill an established measure of food addiction (i.e. the YFAS, Gearhardt et al., 2009) would demonstrate increased AB to food-cues. Indeed, previous research has shown increased attentional allocation to food-cues in those who fulfill the YFAS diagnostic criterion, or have increased food addiction symptomology (Frayn, Sears, & von Ranson, 2016; Meule et al., 2012). Furthermore, YFAS-diagnosed food addiction has been found to moderate the effect of a sad mood induction on AB to food-cues (Frayn, Sears, & von Ranson, 2016). As only seven participants in the current study met the YFAS criteria, we were unable to explore this possibility. In the current study, the YFAS symptom count measure was not associated with AB to chocolate pictures or with DtE ratings for chocolate.

In summary, contrary to our hypotheses, SPFAs did not show increased AB to food-cues, relative to non-addicts, and this was not moderated by hunger condition or the expectancy information. More generally, our findings indicate a key role of state factors, such as reward expectancy and DtE, in determining AB to food-cues. However, AB was not affected by hunger state. Our findings therefore provide partial support for contemporary theoretical models of AB which suggest that *state* factors exert greater influence over AB to reward-related cues (e.g. food), than between-subject *trait* characteristics (Field et al., 2016).

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