Pre- and postprandial variation in implicit attention to food images reflects appetite and sensory-specific satiety.

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Abstract

Implicit attentional processes are biased toward food-related stimuli, with the extent of that bias reflecting relative motivation to eat. These interactions have typically been investigated by comparisons between fasted and sated individuals. In this study, temporal changes in implicit attention to food were assessed in relation to natural, spontaneous changes in appetite occurring before and after an anticipated midday meal. Non-fasted adults performed an emotional blink of attention (EBA) task at intervals, before and after consuming preferred, pre-selected sandwiches to satiety. Participants were required to detect targets within a rapid visual stream, presented after task-irrelevant food (preferred or non-preferred sandwiches, or desserts) or non-food distractor images. All categories of food distractor preferentially captured attention even when appetite levels were low, but became more distracting as appetite increased preprandially, reducing task accuracy maximally as hunger peaked before lunch. Postprandially, attentional capture was markedly reduced for images of the specific sandwich type consumed and, to a lesser extent, for images of other sandwich types that had not been eaten. Attentional capture by images of desserts was unaffected by satiation. These findings support an important role of selective visual attention in the guidance of motivated behaviour. Naturalistic, meal-related changes in appetite are accompanied by changes in implicit attention to visual food stimuli that are easily detected using the EBA paradigm. Preprandial enhancement of attention capture by food cues likely reflects increases in the incentive motivational value of all food stimuli, perhaps providing an implicit index of wanting. Postprandial EBA responses confirm that satiation on a particular food results in relative inattention to that food, supporting an important attentional component in the operation of sensory-specific satiety.

Keywords

hunger, satiation, motivation, cognition, attentional bias

Introduction

A broad range of studies have demonstrated that we possess an innate attentional bias for food stimuli, indicative of a preferential allocation of cognitive resources to the detection of nutritive items within our environment. Moreover, as might be expected, the ability of food to capture our attention is enhanced when our motivation to eat is increased. Thus, while a preferential attentional bias toward food may be evident even in the absence of need (e.g., Garcia-Burgos, Lao, Munsch, & Caldara, 2017; Nummenmaa, Hietananen, Clavo, & Hyönä, 2011), experiments using a variety of spatial and temporal attention tasks have found that hunger induced by fasting increases attentional bias to food-related stimuli in Stroop, visual probe, eye-tracking and attentional blink paradigms (e.g., Castellanos et al., 2009; Channon & Hayward, 1990; Lavy & van den Hout, 1993; Loeber, Grosshans, Herpertz, Kiefer, Herpertz, 2013; Mogg, Bradley, Hyare, & Lee, 1998; Nijs Muris, Euser, & Franken, 2010; Piech, Pastorino & Zald, 2010; Placanica, Faunce, & Soames Job, 2002).

An important consideration when considering how attention to food might vary in relation to meal taking is that satiety is not an absolute phenomenon. The termination of eating of a particular food might be associated with subjective reports of a reduced desire to eat or feelings of fullness, but a recrudescence of the motivation to eat and further consumption are easily induced by the presentation of different, tempting foods. This phenomenon, which relates directly to the impact of the incentive salience and hedonic evaluation of food, is known as sensory-specific satiety (Havermans, Janssen, Giesen, Roefs, & Jansen, 2009; Rolls, Rolls, Rowe, & Sweeney, 1981). Sensory-, or food-specific satiety refers to the observation that the pleasantness of the sight and taste of a food that is eaten to satiety declines compared to other positively-evaluated foods that have not been consumed. Consequently, appetite may be prolonged and overconsumption stimulated by the availability of a variety of, particularly highly palatable, foods: a phenomenon that is apparent in buffet meal situations, and which underlies the division of meals into distinct courses that is found in many cuisines (Hetherington & Rolls, 1996; Remick, Polivy, & Pliner, 2009).

In relation to attentional bias to visual food stimuli, sensory-specific satiety might be predicted to be reflected in changes in the ability of different foods to capture our attention, dependent on their relative motivational (incentive) or emotional (hedonic) salience, and to be linked to the consumption of particular foods. To date, this possibility has been investigated in only a single study (Di Pellegrino, Magarelli, & Mengarelli, 2011). Di Pellegrino and colleagues used a visual probe task to assess attention to pictures of two palatable test foods (crackers and cookies) that were initially rated as having equivalent levels of pleasantness. Attentional bias to the food stimuli was assessed in 6-hour fasted participants, before and after they had eaten to satiety on one of the food types. Before eating, the two foods were able to capture attention to a similar degree. However, after satiation there was a marked attenuation of attentional bias to, and reduction in pleasantness ratings of, the food that had been consumed. Moreover, for the food that was eaten, the greater the reduction in its reported pleasantness, the greater was the reduction in attentional bias. Thus, the authors concluded that the transitory changes in the relative preference for different foods that characterize sensory-specific satiety are mirrored by adjustments to the allocation of visual attention – away from food that has been recently consumed and that is consequently hedonically devalued (Di Pellegrino et al, 2011). For the omnivore, such a mechanism would favour the optimal exploitation of a range of available food resources and promote a varied diet, so avoiding potentially injurious overconsumption of a single food and maximizing the opportunity to meet the requirement for essential nutrients and energy (Di Pellegrino et al, 2011; Kirkham, 2009; Rolls et al., 1981).

The above study also represents the only study in which attentional bias for food has been assessed directly in relation to the transition from hunger to satiety within the same individuals, immediately before and after eating: other studies have used different groups of participants to compare hungry or sated attentional responses; or, when the same individuals have been tested, fasted and fed conditions commonly did not occur in the same experimental session.

In the present study, we were concerned to extend the analysis of motivation-attention interrelationships beyond the simple comparison of fasted or fed states, and investigate the extent to which dynamic changes in attentional bias to food cues are linked, over time, to the rise and fall of eating motivation that naturally precede and follow food consumption at predictable mealtimes. Consequently, we monitored naturalistic temporal changes in these variables over several hours before and after an *ad libitum* lunch, in habitual lunch-eaters who attended the laboratory without any prior restriction on their food intake and who followed their normal breakfasting routine. In addition, we wished to further characterize any attentional correlates of sensory-specific satiety in light of the findings of Di Pellegrino *et al.* (2011). Accordingly, we adopted an emotional blink of attention (EBA) task, in which the presentation of a task-irrelevant, motivationally or emotionally salient distractor image within a rapid serial visual presentation (RSVP) can induce an attentional blink that reduces one's ability to subsequently detect a specific target (Most, Chun, Widders & Zald, 2005). The EBA paradigm is regarded as a powerful measure of stimulus-driven attention, assessing the capacity of salient stimuli to preferentially capture attentional resources (McHugo, Olatunji, & Zald, 2013). More specifically, we adapted the EBA technique of Piech, Pastorino, and Zald (2010) with which they successfully demonstrated that food distractor images more effectively induced an attentional blink in participants when they were fasted overnight, compared to when they were sated.

In the experiment described here, the EBA task was repeated at regular intervals both before and after an *ad libitum* sandwich lunch, in which participants consumed a pre-selected, preferred sandwich type to satiety. Within successive RSVP streams, distractor images consisted of photographs of either the specific type of sandwich that would be eaten at lunchtime, or sandwiches with different fillings that would not be consumed, or pictures of desserts. These two distinct categories were chosen to reflect foods that are likely to be eaten at lunch by our participant population and, being discernibly either savoury or sweet, to reflect the usual course structure of meals and also facilitate detection of sensory-specific effects (Griffioen-Roose, Finlayson, Mars, Blundell & de Graaf, 2010).

Thus, we were able to assess the temporal variation in attention to food in general, against changing levels of pre- and postprandial eating motivation, and also selective adjustments in the relative attentional bias to the different categories of consumed or non-consumed foods that might reflect sensory-specific satiety. We anticipated that as motivation to eat increased as lunchtime approached, food images would become increasingly more distracting, reflecting their greater motivational salience, and lead to lower accuracy in the EBA task. We were also interested in respective temporal changes in attentional capture by the different food types, reflecting relative preference for different foods and, particularly, the foods chosen by the participants for their lunch. Meal consumption and satiation were expected to result in lessened attentional capture by food images, resulting in higher postprandial task accuracy. We also assessed whether sensory-specific satiety might be evident in a greater postprandial reduction in attentional bias, and hence more improved EBA accuracy, on trials when distractors depicted the actual food that had been consumed, compared to images of distinctly different foods (desserts) or other, uneaten sandwich types.

Method

Participants

Twenty-nine adults (12 males, 17 females), aged between 18 and 40 (mean ± SD = 23.4 ± 3.7 years), with a mean BMI of 24.3 ± 4.3, were recruited from the University of Liverpool campus and the surrounding community, using advertisements and opportunity sampling methods. Participants were required to have normal or corrected-to-normal vision, to be non-smokers, non-dieters and habitual lunch eaters. Exclusion criteria included the recent or current use of any medication that might affect appetite or attention, or any food allergy or intolerance. Volunteers were informed that the study was investigating how people's attention to motivationally significant stimuli change over time in relation to fluctuating motivational state, but no specific reference was made to the central focus on changes in attention to food in relation to the motivation to eat. Participants were financially reimbursed for their involvement in the experiment. Ethical approval for the study was obtained from the University of Liverpool's Institute of Psychology, Health and Society Ethics Committee.

Emotional Blink of Attention Task

The study adapted the emotional blink of attention (EBA) paradigm previously reported by Piech, Pastorino & Zald (2010), using a modification of the original software generously provided by Dr Richard Piech.

The EBA task consisted of repeated trials within which the participant was required to detect a target amongst a series of images presented within a rapid, serial visual stream presented on a computer screen, using an E-Prime® program (Psychology Software Tools, Inc, Sharpsburg, PA, USA). On each test occasion, participants were exposed to 4 blocks of 32 streams (trials), with a 1-minute rest interval between successive blocks; the complete sequence took ~12 minutes. In each trial, the visual stream comprised 17 successive images, serving either as a filler, distractor, or target (see Fig. 1). Each image in the stream was presented for 100 ms, with no delay between successive images. Distractor (neutral or food) images could appear randomly at any point within the stream, after the presentation of at least 3 fillers (landscape images). Trials containing the different distractor categories were distributed evenly within each block. Target images (landscape images rotated 90° degrees either clockwise or counter-clockwise) were displayed 200 ms after the onset of the distractor (i.e., 2-lag). At the end of each stream participants were required to indicate, by key press in response to screen prompts, whether they had seen the target and, if they had, whether it was rotated to the left or right. Participants were instructed to answer as quickly as possible. Only trials for which the participant reported seeing the target and correctly indicated its rotation were counted as correct. The reaction times for responses to these questions, and response correctness, were recorded by the software.

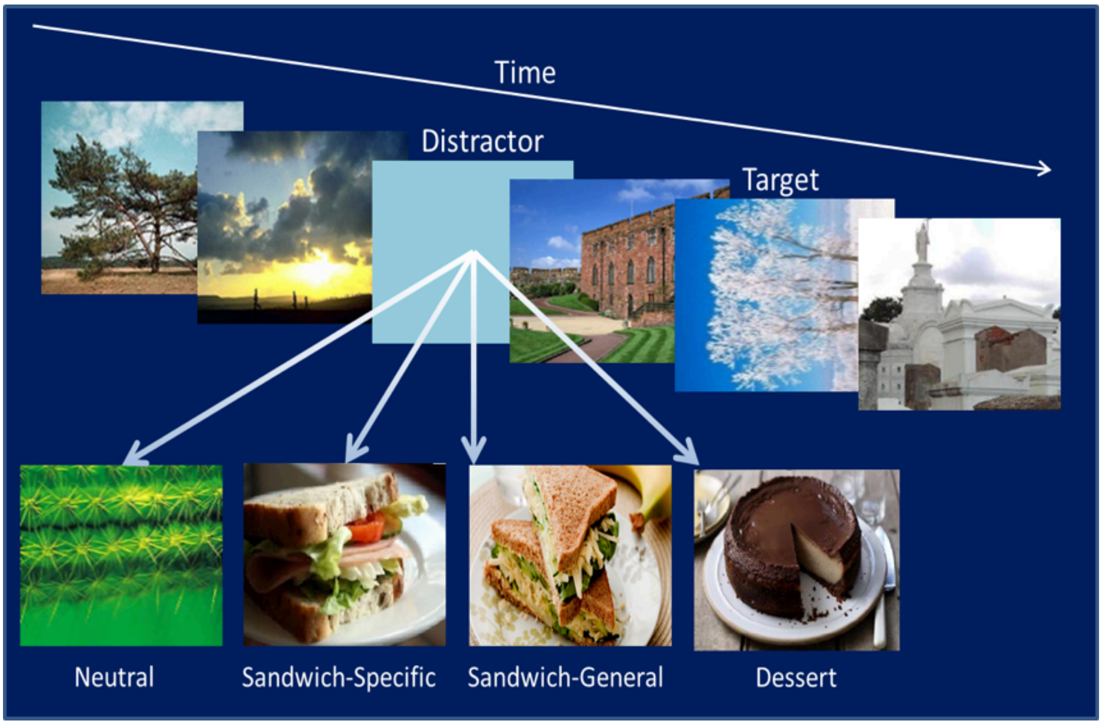

Fig. 1. Representation of the EBA task. On every trial, a stream of 17 consecutive images were each presented for 100 ms. The distractor image belonged to one of 4 categories: neutral pictures, sandwich-specific (photographs of sandwiches with the specific filling

selected by each participant for lunch), sandwich-general (sandwiches with other, non-selected fillings), or dessert. The target was a rotated landscape appearing 2 presentations after the distractor. At the end of each stream, participants responded to onscreen prompts to indicate whether they had seen the target, and the direction of its rotation.

Visual stimuli: A total of 854 colour, luminance-matched, photographic images were used, each presented on screen in a 95 mm wide x 75 mm high format, viewed at a distance of approximately 500 mm. Images were taken from the International Affective Picture System (IAPS) databank (Lang, Bradley, & Cuthbert, 2001), as used by Piech et al. (2010), and supplemented by photographs of food prepared specifically for this study. The fillers were selected from 252 images of landscapes and urban scenes. The targets were drawn from separate banks of similar scenes rotated either 90° to the left (136) or right (135). Neutral distractors were 48 images selected from the IAPS, depicting commonplace objects chosen for their low arousal and neutral valence ratings (Lang, Greenwald, Bradley, & Hamm, 1993). Food distractors belonged to one of three categories: sandwich-specific, sandwich-general, or dessert. Thirty sandwich-specific images represented the particular sandwich type that each participant had selected to eat for their lunch, taken from a range of different perspectives with the filling being easily identifiable in each. Sandwich-general distractors were drawn from 150 equivalent photographs representing the 4 other, non-selected sandwich types. Dessert distractors were selected from 52 photographs of appetizing desserts.

Procedure

Participants were tested singly, arriving at the laboratory at 10:00 for preliminary screening to ensure compliance with inclusion and exclusion criteria, and to complete the informed consent procedure. No specific instructions about eating or food consumption were given before the study, other than to indicate to the participants that they should not bring food to the laboratory as a sandwich lunch was to be provided. Prior to the test session, participants were asked to select their preferred sandwich from a choice of five commonly eaten varieties of filling (bacon, lettuce and tomato; cheese; cheese and pickle; ham; egg mayonnaise). Sandwiches were commercially-prepared by a national supermarket chain, and purchased on the day of testing. The manufacturer's reported energy content ranged between 205 – 225 Kcal 100 g^{-1}. Participants were required to remain within the laboratory for the duration of the experiment, but during the intervals between testing sessions they were allowed to relax in a lounge area where they had access to computers and the internet, a range of reading material and a television.

Initially, participants' height and weight were measured for the calculation of BMI. As classified by BMI, the majority (21) of participants were normal weight; 5 were overweight, 1 was obese and 2 were underweight. They next completed an appetite visual analogue scale (AVAS; adapted from Blundell et al, 2010). The AVAS comprised 4 appetite-related items ('How hungry do you feel?', 'How strong is your desire to eat?', 'How full are you?' and 'How much food do you think you could eat?'), and 8 questions recording levels of general motivation (e.g., 'How strong do you feel right now?', 'How determined are you?'). The questionnaire utilized a 100 mm VAS to record responses to each item, anchored with terms such as 'Not at all' and 'Extremely'. A single AVAS score was derived from the mean of ratings on the 4 appetite items, with a potential maximum score of 100 indicating the highest level of motivation to eat. Additionally, participants completed a valence task in which they were asked to rate the pleasantness of 50 images selected from each of the following categories (10 of each): landscape fillers, and neutral, sandwich-specific, sandwich-general and dessert distractors. The images were rated on a 100 mm VAS, anchored with the terms "not at all pleasant" and "extremely pleasant".

Having completed these initial ratings, participants undertook the first EBA session. Subsequently, over the course of 4 hours, the AVAS and EBA measures were repeated on 7 occasions, each separated by a 40-minute interval. Two hours after the start of testing (from 12:00), participants were allowed 40 minutes to eat lunch, comprising their preferred, pre-selected sandwich, and water to drink. Each participant was provided with 4 identical, pre-weighed sandwiches presented on a plate (average serving weight = 338 ± 4 g; average energy content = 213 ± 4 Kcal 100 g^{-1}), and was invited to eat as much, or as little, as they wanted. Testing recommenced, as described above, after the plates were removed to determine the weight of food consumed. Both before and after lunch, and again after the final test session, participants re-rated the pleasantness of the images originally shown to them at the beginning of the experiment. Finally, the participants were debriefed as to the purpose of the study and released from the experiment.

Data analysis

Data were analyzed to assess: magnitude of each dependent variable at each measurement point; changes from baseline (T1), and changes over successive intervals ($T_n : T_{n+1}$). Data were checked for outliers with responses falling outside k = 2.2, as recommended by Hoaglin and Iglewicz (1987). Analysis of variance was used to analyze temporal trends in data for AVAS and valence across all test sessions. Separate analyses for EBA accuracy and reaction times were conducted, with distractor type and test session as the within-subjects factors, as described in the following sections. Separate analyses were conducted to specifically assess distractor type-dependent changes in EBA accuracy resulting from satiation on the test lunch, by comparing responses at T4 and T5 and also examining the relative (%) change in accuracy from the hungry to sated states. Selected *post hoc* comparisons were conducted using Student's t-test. Data spread was analyzed further using regression model checking and analysis of variance procedures. Pearson's correlation coefficient was also applied to assess covariance between the different variables. Data analysis was conducted with R, using the RStudio® software package (RStudio Inc., Boston, MA, USA).

Results

Appetite

As Fig. 2 illustrates, there was a significant main effect of time, with appetite ratings across the four-hour test period following a clear pattern of typical pre- and postprandial changes ($F (6,196) = 25.88$, $p < 0.001$, $\eta_p^2 = 0.44$). Specifically, participants arrived at the laboratory with low to moderate levels of eating motivation: the baseline AVAS score (mean ± SE) was 37.6 ± 3.8, on a 0 – 100 scale. Subsequently, appetite levels rose incrementally at each successive preprandial measurement point ($F(1,114) = 25.9$, $p < 0.001$), to reach a maximum (64.4 ± 3.6) immediately before the presentation of the lunch, with significant elevation above baseline evident at T3 and T4 ($p < 0.01$). After satiating on their *ad libitum* meal (average intake = 223.8 ± 34.6 g; 481.2 ± 80.7 Kcal), participants displayed the anticipated reduction in motivation to eat: appetite ratings at T5 (15.1 ± 2.9) were significantly lower than before lunch at T4 ($t(28) = 11.63$, $p < 0.001$, $r = .91$). This state of relative satiety persisted after lunch, with only a gradual rise in appetite levels across the remainder of the experiment, with motivation to eat being consistently rated lower than the T1 baseline ($p < 0.01$ at each successive interval).

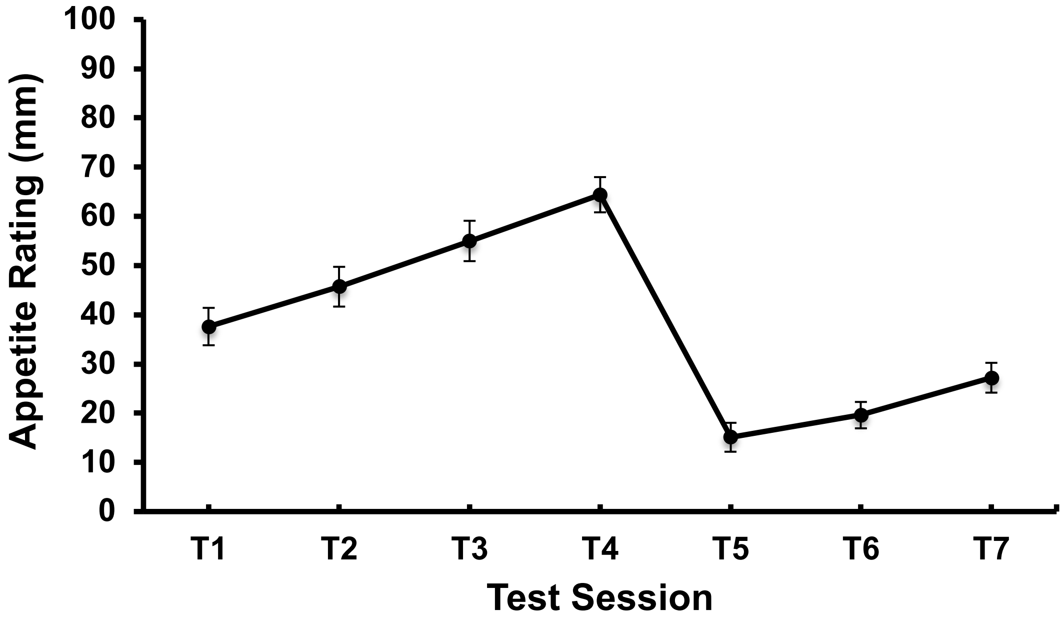

Fig. 2. Mean (± SE) appetite ratings recorded at 40-minute intervals, before and after an *ad libitum* sandwich lunch presented between T4 and T5. Significant differences from either baseline (T1) or pre-lunch (T4) ratings are respectively represented by [a] and [b].

EBA performance - Response accuracy

The primary attentional variable in the study was the accuracy of target detection: i.e., the percentage of trials for streams containing each of the four different distractor types at each test interval in which the target was detected and its direction of rotation correctly identified. A lower accuracy score signifies greater attention capture by distractor images, and consequently a reduced ability to detect the target.

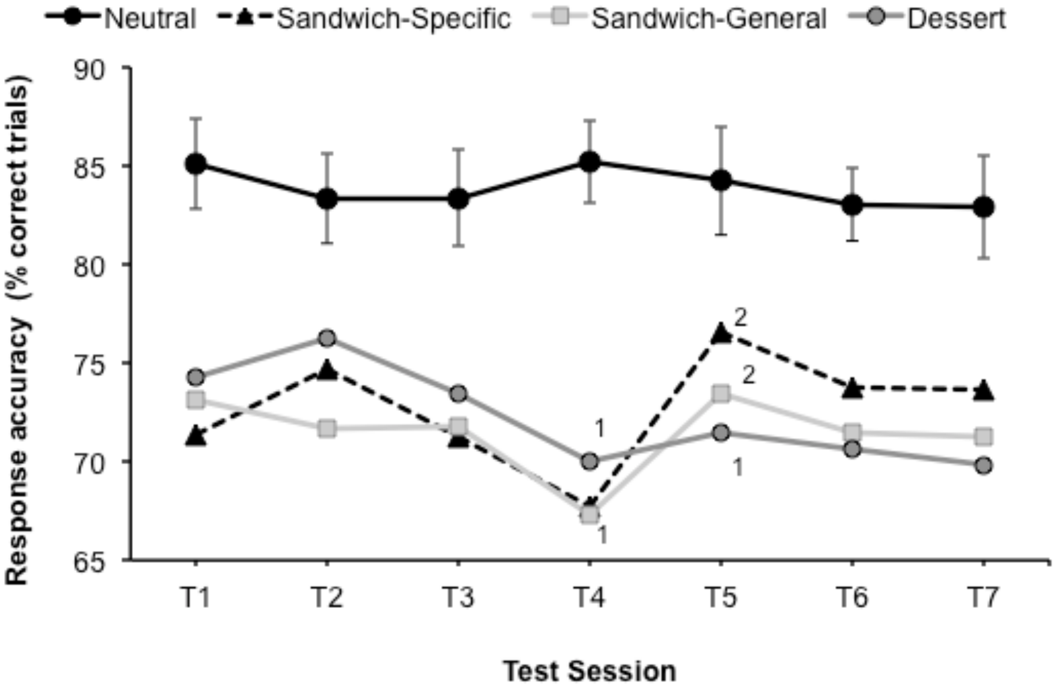

Fig. 3. Response accuracy on the EBA task on successive tests (T1 – T7). Values represent the mean percentage of all trials containing each distractor type in which the target image was correctly identified. A lower value indicates greater attention capture by distractors. For clarity, error bars (SEM) are included for only the neutral images. For T4 and T5 (immediately before and after a sandwich lunch), 1 = significantly different from neutral, 2 = significant postprandial increase in accuracy at T5, relative to T4 (p<0.001 in all cases).

Figure 3 summarizes the changes in response accuracy over time for each distractor type. Preliminary analysis indicated a significant main effect of distractor type, but no test session x distractor interaction. There was a clear distinction between accuracy levels for trials with neutral distractors compared to those with food distractors across the whole test period ($F(3,784) = 29.8$, $p<0.001$, $\eta_p^2 = 0.1$). Accuracy for trials with neutral distractors was initially high, and remained relatively constant across the whole experiment. In contrast, irrespective of their specific category, food distractors consistently reduced participants' ability to identify the targets. Notably, in the preprandial period, there was a general decline in accuracy for all of the food distractor categories – particularly evident between T2 – T4 ($F(15,336) = 4.54$, $R^2 = 0.10$, $p < 0.001$). The lowest accuracy levels for food distractor trials (indicating the greatest attentional capture) occurred in the last EBA session before lunch (T4). Over this period, there was a significant decline in accuracy for dessert ($t(28) = 2.95$, $p = 0.003$), sandwich-specific ($t(28) = 3.05$, $p = 0.002$) distractor trials. By contrast, accuracy for neutral distractors was unaffected (t(28) = 0.63, p = 0.53). The accentuation of preprandial attentional bias to food thus closely matched the rise in motivation to eat over the same period, with all food stimuli being maximally distracting when the participants were most hungry.

After lunch, when participants were sated, there was a very distinctive pattern of responding, with accuracy being dependent on the specific content of the food distractors. Notably, attentional capture by sandwich-specific distractors (i.e., those depicting the actual sandwich type that had been eaten) was markedly lower at T5 than before lunch (i.e., EBA accuracy increased). Subsequently, accuracy for sandwich-specific distractors returned to the levels seen in the early preprandial period. A smaller post-lunch improvement in accuracy was observed for sandwich-general distractors, with the percentage of correct trials at T5 returning to T1 levels, and stabilizing for the remainder of the experiment. In contrast to the changes noted for sandwich distractors, accuracy for dessert distractors showed no post-lunch improvement, but rather remained at the preprandial (T4) level until the end of testing.

Specific comparisons between response accuracy immediately before (T4) or after lunch (T5), when the respective maximum and minimum levels of eating motivation were recorded, confirm the varied influence of distractor type (F(3,224) = 11.02, p < 0.001, η_p^2 = 0.13) and time (F(1,224) = 4.42, p = 0.04, η_p^2= 0.02). Before the meal, when participants were most hungry, each category of food distractor was similarly distracting (F(3,112) = 9.86, p < 0.001, η_p^2 = 0.21): accuracy levels for all food distractors were reliably lower than for the neutral distractors (p < 0.001 in each case), but there was no difference in attentional bias between streams containing the different food categories (p > 0.95). By contrast, when participants were sated, response accuracy altered differentially according to the type of food distractor. Compared to pre-lunch measures, accuracy was significantly improved for both sandwich-general (t(28)= 1.8, p < 0.001, *r* = 0.32) and, more particularly, sandwich-specific (t(28) = 3.82, p < 0.001, *r* = 0.59) distractor streams. Consequently, at T5 accuracy levels for sandwich-specific and sandwich-general distractor streams were no longer reliably lower than for neutral distractor streams (p = 0.55 and 0.6, respectively). Dessert distractors, however, did retain their preprandial distracting potency when participants were satiated, and accuracy for these streams at T5 remained significantly lower than for those with neutral distractors (p = 0.02).

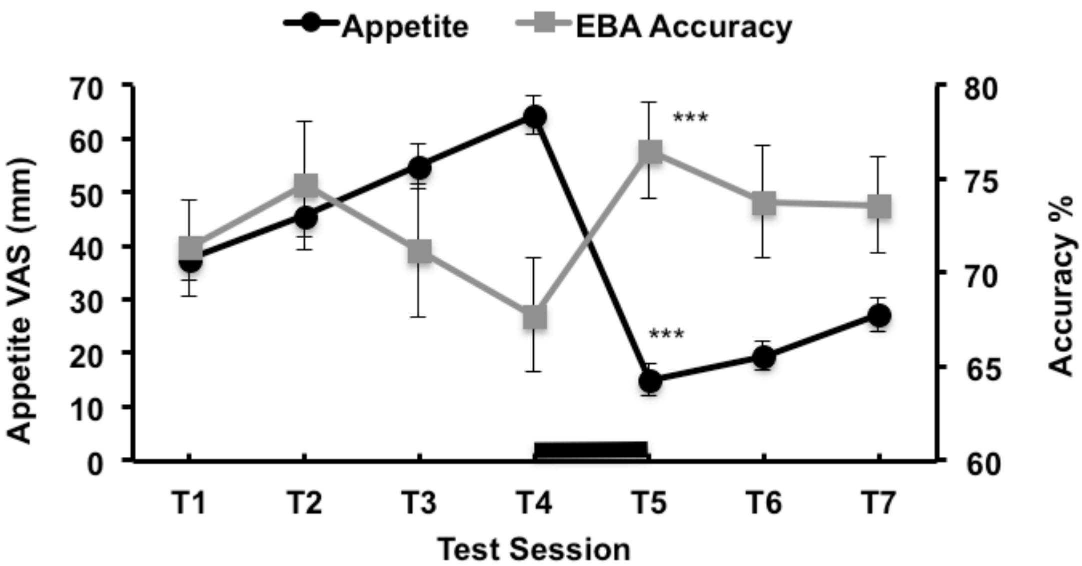

Fig. 4. The relationship between motivation to eat and attention capture by photographs of the preferred sandwich consumed at lunch (sandwich-specific distractors) at each test interval, before and after lunch (between T4 and T5). *** indicates significant difference between T4 and T5; $p < 0.001$.

Examination of the relative change in EBA accuracy from before to after lunch (T4 to T5) more clearly reveals the differential effect of satiation on the attentional bias to each distractor type ($F(3,112) = 3.17$, $p = 0.03$, $\eta_p^2 = 0.08$). In particular, it can be seen that the postprandial reduction in attentional capture by sandwich-depicting distractors was more pronounced for those that specifically illustrated the kind of sandwich that had actually been eaten. Thus, for sandwich-specific streams there was a marked ~20% mean increase in correct responses when sated ($t(28) = 2.9$, $p < 0.01$, $r = 0.48$). A more modest average increase in accuracy of 11% was observed for sandwich-general streams. Furthermore, between T4 – T5 the relative increase in EBA task accuracy was closely related to the relative decline in motivation to eat for sandwich-specific distractor streams ($r(27) = 0.43$, $p < 0.001$), but not for sandwich-general streams ($r(27) = 0.04$, $p = 0.80$). The reciprocal relationship between relative motivation to eat and attention capture by sandwich-specific distractors is illustrated in Fig. 4. Accuracy for neither neutral nor dessert distractor streams showed any appreciable change from T4 to T5 (-0.7% and 3%, respectively).

Reaction time

Analysis of reaction times (Fig. 5) revealed a significant effect of time (F(6,784) = 34.03, p<0.001, η_p^2 = 0.21), but not distractor type (F(3,784) = 0.13, p = 0.94, η_p^2 < 0.01), nor any interaction (F(18,784) = 0.07, p = 1.00). Reaction times for trials with all distractor types were similar at each interval, and showed a gradual reduction from T1 – T3, before stabilizing; possibly reflecting a general practice effect (which is accommodated for in the analysis of EBA accuracy, above).

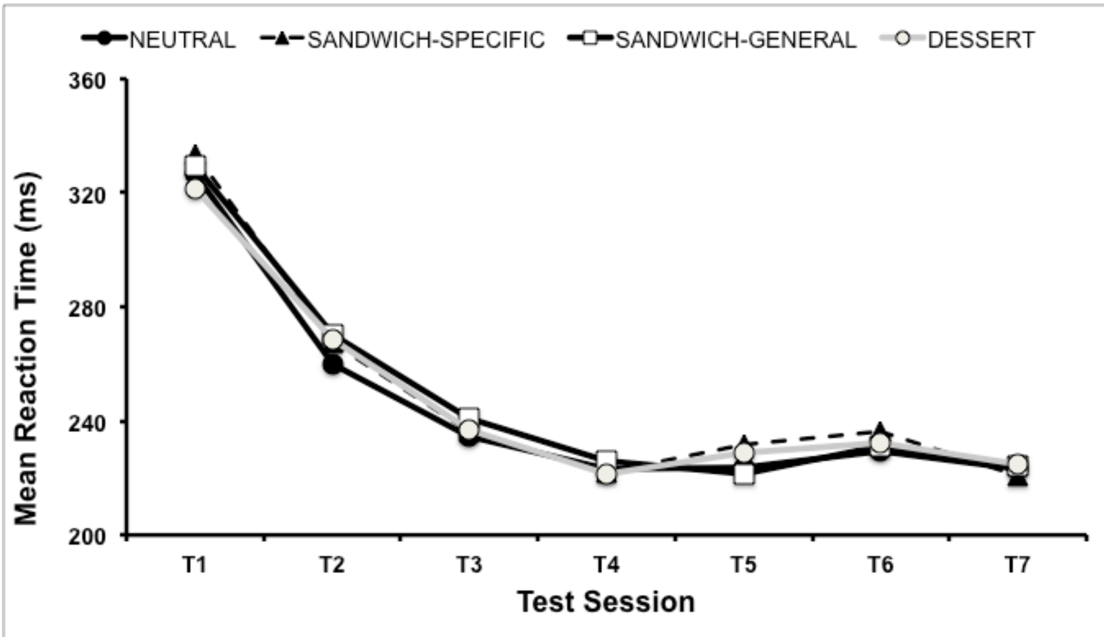

Fig. 5. Average reaction times for correct trials with streams containing the different distractor types at successive tests.

Image Valence

Examples from each image category (fillers and the four distractor types) were rated for pleasantness at intervals during the experiment (T1, T4, T5 and T7). Ratings differed between image types (F (4,580) = 23.83, p < 0.001, η_p^2 = 0.14), and changes were apparent across the course of the experiment (F (3,580) = 2.88, p = 0.04, η_p^2 = 0.01), but no interaction was evident (F (12,580) = 1.21, p = 0.28, η_p^2 = 0.02). Initially, neutral, dessert and sandwich-specific distractor images had similar ratings, and all were rated as more pleasant than sandwich-general images – possibly reflecting the participants' lower preference for sandwich fillings different from that selected for their lunch. Successive ratings were relatively constant for the neutral and dessert distractors. As Fig. 6 illustrates, the most notable changes evident during the experiment were respective 19% and 15% reductions in the valence ratings of sandwich-specific and sandwich-general images following satiation, from T4 to T5 (F(4,145) = 3.86, p = 0.01, η_p^2 = 0.10).

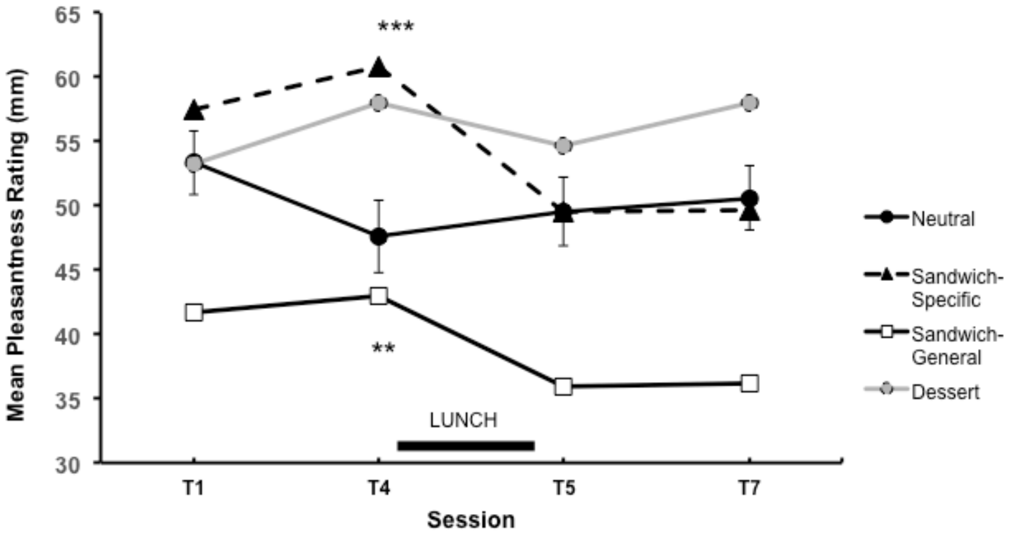

Fig. 6. Valence (pleasantness) of distractor images was rated at baseline (T1), before (T4) and after (T5) lunch, and at the end of the study (T7). Values are means obtained from individual 100 mm VAS ratings of 10 images of each category. For clarity, error bars (SEM) are included for only the neutral images. Asterisks indicate significant differences between T4 and T5 ratings of images representing consumed and non-consumed sandwiches (** p < .01; *** p < .001).

Discussion

There have been several previous reports, using a variety of experimental methods, that hunger results in an increased attentional bias to food stimuli (e.g., Castellanos et al., 2009; Channon & Hayward, 1990; Lavy & van den Hout, 1993; Loeber et al., 2013; Mogg et al., 1998; Nijs et al., 2010; Piech et al., 2010; Placanica, et al., 2002; Tapper, Pothos, & Lawrence, 2010). However, in the majority of cases hunger was experimentally induced by, often lengthy, periods of food abstinence. Additionally, only a single study has directly compared attention to food in the same individuals both before and after a meal (Di Pellegrino et al., 2011). Here, we demonstrate that appetite-related, temporal changes in attention to food can be easily detected in individuals who are following their normal, everyday eating patterns – without the imposition of fasting or other constraints on food intake. Our findings are therefore representative of the daily fluctuations in eating motivation that reflect the more typical influence of habit and learned cues on meal-taking, rather than need induced by energy imbalance (De Castro, 1996). Thus, in habitual lunch-eaters – attending the laboratory having followed their usual breakfast routine, the capacity for food images to capture attention in the EBA task was found to be strongly related to the spontaneous changes in appetite that naturally accompany the approach of an anticipated midday meal, and that follow its consumption and the onset of satiety.

In line with earlier research indicating a general attentional bias toward food cues (Nummenmaa et al., 2011), we found that all categories of food distractors reliably captured attention at the earliest stage of testing, even though participants reported only moderate appetite levels. Subsequently, as appetite progressively increased preprandially, attentional capture by food distractors also increased. Immediately before lunch, when motivation to eat was at its highest, interference with target identification was also maximal. Moreover, at that point, each category of food distractor caused a similar reduction in accuracy. Our data therefore confirm that hunger increases attention to food, but also indicate that this change occurs irrespective of the particular qualities represented in the different food stimuli – apparent sensory properties, energy content, palatability or relative preference. This interpretation is consistent with the findings of a visual probe study reported by Tapper, et al. (2010), who found that hunger increased attentional bias to food pictures regardless of whether they were classed as appetizing or bland. Such a generalized, undiscriminating, increase in the salience of, and allocation of attention to food *per se* might be expected in order to orient the individual toward those aspects of the environment that may directly address a specific biological need or reflect a particular motivational state.

By contrast to the general increase in attention to food observed preprandially, when participants were sated after their sandwich lunch the effects of food distractors on EBA responses were more nuanced. As anticipated, after satiating there was a general tendency for food images to become less distracting as appetite level fell to its minimum. However, the degree of post-satiation attentional capture by food images was clearly dependent upon the particular type of food represented. Most notably, distractors depicting sandwiches displayed a marked decrease in their ability to capture attention after satiation, while dessert-depicting distractors remained almost as potent as before the lunch. Moreover, the satiety-related reduction in attentional capture for sandwich-depicting distractors was observed to be greater when the images specifically represented the actual sandwich type that had been consumed. Thus, in accord with the report by Di Pellegrino et al. (2011), visual attention to food cues appears not to be modulated indiscriminately by the transition from hunger to satiety – to render all food less distracting; but exhibits the capacity to distinguish between foods that have been recently consumed from those which have not. Moreover, our data indicate that, postprandially, early processing in visual attentional systems is not only sensitive to differences between distinct food types with marked featural differences or disparate sensory attributes, but also rapidly resolves more subtle distinctions between items within a single food category that share common prominent visual features.

The selective changes in postprandial attention to different food categories arguably reflect the operation of sensory-specific satiety. This phenomenon has been hypothesized to represent an evolved mechanism to both prevent overconsumption of a single food source – which might be potentially injurious if eaten exclusively, and to facilitate intake of a varied diet in support of nutritional integrity (Rolls, et al., 1981). Central to the concept of sensory-specific satiety is the selective hedonic devaluation of a food that has been consumed, relative to other, uneaten foods – for which pleasantness may remain undiminished after a meal (Rolls, Van Duijvenvoorde, & Rolls, 1984).

Previously, using a dot-probe paradigm, Di Pellegrino and colleagues (2011) showed that after selective satiation on one of two kinds of palatable cookies, perceived pleasantness and attentional bias specifically decreased for the eaten food but not for the other. They hypothesized that attentional bias thus reflected the relative hedonic value of the respective stimuli, with the selectively reduced bias reflecting the devaluation of the eaten food. In support of that notion, in the present study we also observed that postprandial changes in attentional capture by food stimuli matched relative changes in explicit ratings of their attractiveness. Specifically, there were reliable reductions in the ratings of photographs of sandwiches, and this change was most marked for those depicting sandwiches with the particular filling type consumed at lunch. By contrast, no postprandial devaluation in the ratings of dessert images was evident, and these items retained their ability to capture attention as effectively after lunch as before it.

Di Pellegrino et al. (2011) argued that their findings support a general principle that "motivational guidance of attentional resources… reflects accurate online assessment of the hedonic value of the various stimuli present in the environment" (Di Pellegrino et al., 2011; page 567). However, while our data support the postprandial devaluation of the specific food eaten to satiety (albeit using the valence task as a proxy for more meaningful, actual ratings of taste pleasantness), our preprandial observations of alterations to attentional and valence measures may suggest an alternative account. Thus, although there were differences between ratings for the different distractor categories, the relative pleasantness of each food type showed no appreciable change over the course of the morning, even as appetite increased and food distractors became more effective at capturing attention. In fact, images of non-preferred sandwiches (which participants had not selected to eat) were actually rated as less pleasant than neutral, non-food images, while nonetheless capturing attention to the same extent as the other preferred foods immediately before lunch – as well as being markedly more distracting than the non-food stimuli. In this light, rather than reflecting allocation of resources through a purely hedonic evaluation of stimuli ('liking'), the generally enhanced attentional bias to *any* food as hunger increased preprandially may perhaps be better regarded as an implicit index of 'wanting'; i.e., the incentive motivational value of a stimulus that is distinct from its hedonic impact, and which can guide the pursuit of a goal even in advance of any hedonic experience of it (Berridge, 2004).

Thus, in addition to an intrinsic, general tendency to attend to food cues, we have observed both a preprandial, hunger-related increase in attention capture by all food stimuli, and a postprandial capacity to rapidly distinguish between, and selectively attend to, different foods depending on whether or not they have recently been consumed to satiety. These observations suggest that attentional resources can be selectively diverted to subserve both a general search for nutritive substances that is enhanced in times of need (or in anticipation of food availability) or – after satiation on a particular food, to respond only to novel foods or those which have high hedonic value, perhaps linked to their apparent high energy content. The observed pattern of changes in attentional bias likely reflects the operation of mechanisms that evolved to serve what might be regarded as the primary fundamental biological priority – to obtain energy and nutrients within an unpredictable food environment: enabling us to scan the environment and be alert to all sources of nutrients even in the absence of immediate energetic imbalance and when levels of eating motivation are low; facilitating detection and approach to food in times of need, as motivation to eat increases; promoting a varied, nutritionally optimized diet by reducing attention to recently eaten foods while retaining detection of alternatives; and being especially sensitive to the appearance of foods, such as fruits, that can provide easily assimilable energy for immediate sustenance or conversion to long-term stores as protection against future energy deficit.

Visual attention may play a critical role in the motivation and orientation of appetitive behaviour, contributing to both its initiation and termination by mediating the relative incentive value of need-relevant stimuli. The automatic processes detected here, with the selective filtering and transfer of food stimuli into conscious awareness, can thus divert us from other activities to exploit opportunities to feed, or to permit potential nutrient sources to be registered for later exploitation. Arguably, especially for nutritionally replete individuals in a well-provisioned food environment, satiety might be regarded as a state of relative inattention to food, permitting attentional resources to be redirected and allocated instead toward environmental stimuli that match other motivational imperatives. However, that foods with high intrinsic hedonic value, typically reflecting their energy-dense nature, retain their ability to capture attention even when an individual is sated has obvious implications for understanding the prevalence of overconsumption in our current obesogenic environment, with its numerous cues for a variety of appetizing, calorie-rich foods.

Conclusion

The current findings confirm the utility of the EBA method to provide an accurate, implicit measure of the salience of motivation-specific stimuli in line with dynamic, naturalistic fluctuations in motivational state. We have shown for the first time that temporal changes in attention to food match the continuing alterations in motivation to eat that naturally occur in advance of an anticipated meal, and after satiation. Importantly, using this method, we have shown that increased attention to food can be detected without the imposition of fasting, and does not require extreme variation in levels of hunger to be observed. Moreover, we have confirmed that sensory-specific satiety has a clear attentional component, demonstrating postprandial changes in stimulus-driven, bottom-up engagement of attention to different food stimuli (Di Pellegrino et al., 2011; McHugo, et al., 2013). Our data also strongly suggest that attentional systems are able to rapidly discern, and selectively filter, specific visual aspects of food stimuli – assigning cognitive resources in accord with whether a stimulus is identical to the food on which we have recently sated, represents a different food within the same general category, or is an unrelated food which retains intrinsic incentive value. Overall, the present findings strengthen support for an important role of selective visual attention in the guidance of motivated behaviour, and specifically in eating motivation. The EBA technique thus provides opportunities for further investigation of the interaction of attentional mechanisms with motivational, hedonic, environmental, experiential and other factors in relation to eating behaviour and food intake.

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