Feast Your Eyes:
Hunger and Trait Reward Drive Predict Attentional Bias for Food Cues

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Appraisal theories of emotion predict that the relevance of a stimulus to a person's needs and goals influences attentional allocation. We used a modified visual probe task to examine the influence of hunger and trait reward drive on food-related attentional bias. Both hunger and trait reward drive predicted degree of attentional "disengagement" from food images at short (100 ms), but not long (500, 2,000 ms) stimulus durations. Effects of hunger were found for both bland and appetizing foods, while effects of reward drive were restricted to appetizing foods. Our findings extend previous research showing delayed "disengagement" from threat-related stimuli, suggesting that both organismic- and goal-relevance are key biasing factors in attentional competition.

Keywords: appraisal theory of emotion, attention, biased competition, reward, value

Given capacity limitations, a critical function shared by both attentional and emotional processes is to enhance the processing of pertinent events. Appraisal theories of emotion suggest that an early "relevance appraisal" determines the extent to which a stimulus is relevant to the individual's goals or well-being, which in turn dictates subsequent attention allocation (Sander, Grandjean, & Scherer, 2005).

Threat-related stimuli can bias attention allocation, such that their processing is enhanced (Vuilleumier, 2005). Some claim a "privileged" status for threat-related stimuli (Öhman & Wiens, 2004). One source of evidence comes from studies using the visual probe task. In this task, threat stimuli are task-irrelevant, and participants must detect a neutral visual target (probe), that can appear at one of two possible locations, replacing either a threat stimulus ("congruent" trials) or a neutral stimulus ("incongruent" trials). Attentional allocation is measured by probe detection time. If threat cues influence attentional allocation, this results in facilitation of target processing in congruent trials or distraction from target processing in incongruent trials. Such influences on performance are found using various threat cues (Bar-Haim, Lamy, Pergamin, Bakermans-Kranenburg, & van IJendoorn, 2007). However, findings from the visual probe task are ambiguous. The traditional attentional bias index is calculated by subtracting mean reaction times (RTs) to probes replacing threat stimuli, from mean RTs to probes replacing neutral stimuli. A positive score may result from either fast responses to probes replacing threat stimuli ("orienting") and/or slow responses to probes replacing neutral stimuli ("disengagement").

Koster, Crombez, Verschuere, & De Houwer (2004, 2006) adapted the visual probe task to differentiate these two possibilities, by adding trials with two neutral cues. "Heightened orienting" toward threat results in faster responses to probes replacing the location of the threat stimuli (in threat-neutral pairs) compared to probes replacing neutral stimuli (in neutral-neutral pairs). Difficulties in "disengaging" from threat results in slower responses to probes replacing neutral stimuli, in threat-neutral pairs, compared to probes replacing neutral stimuli in neutral-neutral pairs. Koster et al., using 500 ms stimulus presentations, found evidence of delayed disengagement from threat. These and similar findings (e.g., Fox, Russo, Bowles, & Dutton, 2001; Yiend & Mathews, 2001; Georgiou et al., 2005; Salemink, van der Hout, & Kindt, 2007; but see Mogg, Holmes, Garner, & Bradley, 2008) have been interpreted within a serial model of attention postulating subsequent stages of disengagement, shifting, and engagement of attention (Posner, Walker, Friedrich, & Rafal, 1984), with anxiety impacting a distinct disengage mechanism.

Rather than being threat-specific, appraisal theory predicts that motivationally relevant stimuli per se bias attention. Important support for this suggestion may come from studies of attentional bias for food stimuli. If attentional bias (AB) reflects the biological value attached to stimuli, food-related AB should be pronounced in hungry individuals. Mogg, Bradley, Hyare, and Lee (1998), using the dot-probe task, found that hungry (compared to sated) individuals were more likely to show an AB for food words. However, their study did not differentiate between faster orienting or delayed disengagement, and also utilized a median-split design to define hunger, an approach that can be problematic (MacCallum, Zhang, Preacher, & Rucker, 2002, see discussion). Further, they used a stimulus duration of 500 ms which is at the upper limit of estimates of both the dwell time of attention (Bundesen & Habekost, 2008), and the relevance appraisal process (Sander, Grandjean, & Scherer, 2005).

Here, we extend the work of Mogg et al. (1998) in several ways. First, we assess AB at three stimulus durations (100, 500, 2,000 ms). Second, rather than words, we use more salient pictures. Third, we include pairs of neutral pictures, allowing us to distinguish between bias resulting from delayed disengagement versus enhanced orienting (Koster et al., 2004). Fourth, we utilized a regression, rather than median-split design. And fifth, we examine AB to appetizing and bland foods separately (e.g., potato chips vs. rice cakes). Additionally, we examine the impact of trait reward drive, a facet of reward sensitivity (Carver & White, 1994), linked to anticipation of reward from eating (Franken & Muris, 2005), a preference for sweet and fatty foods, and a higher body mass index (BMI; Davis et al., 2007).

If both biological- and goal-relevance determine AB, we would expect (a) hunger to predict AB to food stimuli, especially at short cue durations (500 ms or less) within attentional dwell time; (b) reward drive to predict AB for appetizing foods, especially at short cue presentations. Given that anxiety primarily delays attentional disengagement, such biases may be particularly linked to delayed disengagement.

Method

Participants

There were 105 participants (69 women, mean age 23 years) recruited from Swansea University. All were native English speakers, were not vegetarian and had normal or corrected-to-normal vision. Participants received a small remuneration for participation. Ethical approval was provided by the local University Psychology Department Research Ethics Committee.

Stimuli and Materials

The stimuli for the visual probe task consisted of 70 different color photographs, 10 of which were of appetizing foods (e.g., cookies, potato chips), 10 of which were of bland foods (e.g., rice cakes, lettuce), and 50 of which were household (neutral) items. Pictures had previously been rated by a separate group of participants as falling into these categories. Each food picture was matched for approximate shape and jpeg size to a neutral picture (e.g., hamburger was paired with a CD player, Brussels sprouts with cotton wool balls). Thus, there were 10 appetizing-neutral pairs and 10 bland-neutral pairs. An additional 10 neutral pictures, matched to five of the appetizing pictures, formed five appetizing-matched neutral-neutral pairs and a further 10 neutral pictures, matched to five of the bland pictures, formed five bland-matched neutral-neutral pairs. The remaining 20 neutral pictures made up 10 neutral pairs for use as practice and buffer trials.

Hunger was assessed by asking participants, 'How hungry are you at the moment?' (Scored on a 100 mm visual analogue scale, anchored by "Not hungry at all" and "Extremely hungry"; Mogg et al., 1998). Reward drive was assessed using the Behavioral Activation Scale (BAS) drive subscale (BAS-d; Carver & White, 1994). This consists of four statements (e.g., 'I go out of my way to get things I want') that participants rate on a 4-point scale as true or false for them. Relative to the other BAS subscales, BAS-d is a clearer measure of generalized reward expectancies (Caseras,

Avila, & Torrubia, 2003), and uniquely predicts neural activity to appetizing food images (Beaver et al., 2006).

Procedure

Participants took part in the study between 9 a.m. and 7 p.m. Those who took part between 9 a.m. and 3 p.m. were asked to fast after 9 a.m. Those who took part from 3 p.m. were asked to fast after 2 p.m.

After completing the hunger scale, participants completed the visual probe task. This was presented using SuperLab on a fast PC. Participants were seated at a desk, 100 cm away from a 45 cm monitor. Each trial began with a central fixation cross displayed for 500 ms. This was replaced by one of the picture pairs, displayed side by side. The pictures were ~50 mm in height and width, depending on their shape. There was a distance of 60 mm between the fixation cross and the center of each image. The pictures were displayed for either 100, 500, or 2,000 ms and were replaced by a probe (a square measuring 2 mm $\times$ 2 mm) that was displayed in the location of one of the pictures. Participants were instructed to fixate the central cross at the start of each trial and identify the location of the probe (either left or right), as quickly and as accurately as possible, by pressing either the far left-hand key or far right-hand key on a Cedrus RB-730 response box. The probe was displayed until the participant made a response. There was an intertrial interval of 500 ms.

The task began with 10 practice trials. These were followed by instructions informing participants that the real trials were about to commence, four buffer trials (i.e., 'warm-up' trials, the data for which were not analyzed), 120 critical trials at 100 ms exposure duration, 120 critical trials at 500 ms, and 120 critical trials at 2,000 ms. The 30 pictures pairs (10 appetizing, 10 bland, 10 neutral) were presented four times at each of these durations. Picture and probe location were counterbalanced for each pair. For the food-neutral pairs, congruent trials were those in which the probe replaced the food picture and incongruent trials were those in which the probe replaced the neutral picture. Critical trial pairs were presented in a new random order for each participant. Following the task participants completed other measures including BAS-d and reported whether they were currently dieting to lose weight.

Results

Thirteen participants (all women) reported currently dieting to lose weight. Given potential differences in food-related AB among dieters (Tapper, Pothos, Fadardi, & Ziori, 2008) they were excluded. Our treatment of outliers followed a two-stage process. First we examined and excluded errors and outliers at the individual trial level (i.e., for individual RT scores) (Ratcliff, 1993). To achieve this trials with errors (1.85% of data, $SD = 1.98$) or with RTs <100 or >4,000 ms were removed. Means and SDs were then calculated for each participant, for each of the 18 trial types (bland congruent, bland incongruent, appetizing congruent, appetizing incongruent, bland-matched neutral, appetizing-matched neutral, at each of the three exposures). RTs greater than 3.5 SDs from the participant's relevant trial type mean were discarded. A total of 2.39% ($SD = 2.58$) of data were removed in this way.

Second we examined and excluded outliers in relation to trial types and AB scores. Outliers here are likely to reflect atypical influences at the participant level (e.g., poor concentration). Such scores violate assumptions of parametric statistical tests (Osborne & Overbay, 2004). Since we examine means from both trial types and attentional bias scores in our analyses, it is important that we exclude outliers for both these sets of data. As such means and *SD*s were first calculated across all participants for each of the 18 trial types. Outliers were defined as data >3.5 *SD*s from the mean. Data from two participants were outliers in a majority of the 18 trial types (15 and 17). To avoid biasing subsequent outlier calculations, both these participants were removed before further calculations. Means and *SD*s were then recalculated and two scores removed as outliers (from bland incongruent trials at 100 ms and from appetizing incongruent trials at 100 ms). This reduced the sample to 90 participants for 500 and 2,000 ms exposures and 89 participants for 100 ms exposures.

For each participant, AB for bland and for appetizing foods at each of the three exposures was then calculated by subtracting mean RT for congruent trials from mean RT for incongruent trials. Five outliers were removed resulting in sample sizes for AB scores of 88 for 'appetizing 100' (appetizing foods at 100 ms), 'bland 100' and 'appetizing 2,000', 89 for 'bland 500', and 90 for 'appetizing 500' and 'bland 2000.' Orienting scores were calculated for each of these bias scores by subtracting relevant congruent trials from relevant neutral trials (e.g., subtracting appetizing 100 incongruent from palatable-matched neutral 100) and disengagement scores by subtracting relevant incongruent trials from relevant neutral trials.

To examine AB for appetizing foods across the whole sample, three paired *t* tests were used to compare congruent trials with relevant incongruent trials. As predicted there was a significant difference (i.e., an AB) for appetizing foods at 100 ms, $t(88) = 2.83, p < .01$ ($M = 395, SD = 60$ vs. $M = 386, SD = 62$ for incongruent and congruent trials, respectively, Cohen's $d = 0.30$). There were also significant differences at 500 ms, $t(89) = 5.24, p < .001$ ($M = 401, SD = 54$ vs. $M = 387, SD = 56$, Cohen's $d = 0.56$), and at 2,000 ms, $t(89) = 5.35, p < .001$ ($M = 393, SD = 60$ vs. $M = 377, SD = 50$, Cohen's $d = 0.57$). Mean RTs for appetizing matched neutral trials were 384 ($SD = 53$), 393 ($SD = 60$), and 382 ($SD = 54$) for 100, 500, and 2,000 ms, respectively. Paired *t* tests comparing these RTs with relevant congruent and incongruent RTs indicated that the bias at 100 ms resulted from delayed disengagement, $t(88) = 4.31, p < .001$, Cohen's $d = 0.46$ rather than enhanced orienting, $t(88) = 0.91$, NS. This was also the case at 500 ms, $t(89) = 3.26, p < .005$, Cohen's $d = 0.35$ for disengagement, $t(89 = 1.57$, NS for orienting). However, at 2,000 ms there was evidence of both delayed disengagement, $t(89) = 3.98, p < .001$, Cohen's $d = 0.42$ and enhanced orienting, $t(89) = 2.03, p < .05$, Cohen's $d = 0.22$.[1]

Hunger was scored from 0–100 by measuring mm from the left-hand side of the scale and, across the whole sample, showed a mean of 40.31 ($SD = 26.34$). BAS-d was scored from 4–16 by computing the sum of the four items and showed an overall mean of 10.73 ($SD = 2.12$). To examine associations between these two predictors and AB scores, correlation coefficients were calculated. These showed significant correlations between hunger and appetizing 100 ($r = .22, p < .05$), and between BAS-d and appetizing 100 ($r = .23, p < .05$). There was also a trend-significant corre-

lation between hunger and bland 100 ($r = .20, p = .058$). These correlations are of a similar magnitude to those reported by Salemink et al. (2007) for the effects of anxiety on disengagement from threat-related stimuli.

Further exploration of the two significant correlations was conducted by substituting the overall bias scores with relevant scores for orienting and disengagement. For hunger, the correlation with appetizing 100 orienting ($r = .08$), was significantly less than with appetizing 100 disengagement ($r = -.15$) (Hotelling-Williams test, $t(89) = .97, p = .052$).

For BAS-d, there was a significant negative correlation with appetizing 100 disengagement, ($r = -.28, p < .01$), indicating that at 100 ms participants with higher reward drive were taking longer to disengage their attention from the appetizing food stimuli. There was no correlation between BAS-d and appetizing 100 orienting ($r = -.01$). There was a significant difference between these two correlations, $t(89) = 2.36, p < .05$.

To determine whether these results were specific to 100 ms and to appetizing foods, the significant correlations described above were compared with correlations at other exposures and with bland foods at 100 ms (see Table 1). As shown in Table 1, the correlation between BAS-d and disengagement from appetizing foods at 100 ms was significantly different from the correlation between BAS-d and disengagement from appetizing foods at 500 ms and at 2,000 ms. It was also significantly different from the correlation between BAS-d and disengagement from bland foods at 100 ms. These results suggest that the association between BAS-d and delayed disengagement was specific to appetizing foods at 100 ms. In contrast, the correlation between hunger and overall bias for appetizing foods at 100 ms was not significantly different from correlations at 500, 2,000, or bland foods at 100 ms. Given the absence of difference between bland and appetizing foods, overall food bias, orienting and disengagement scores were computed by taking the mean of the bland and appetizing scores (one outlier was excluded for overall bias at 100 ms, one for orienting at 100 ms, one for disengagement at 100 ms, and one for disengagement at 2,000 ms). Hunger showed a significant correlation with attentional bias for food at 100 ms ($r = .26, p < .05$), but not at 500 ms ($r = -.07$, NS) or 2,000 ms ($r = .15$, NS). Further examination of the 100 ms duration revealed a significant negative correlation between hunger and speed of disengagement from food stimuli ($r = -.25, p < .05$), but no significant correlation between hunger and orienting ($r = .15$, NS). Comparison of correlations (see Table 1) showed that the former was significantly different from the correlation between hunger and disengagement at 500 ms but not at 2,000 ms.

Finally, there was no correlation between BAS-d and hunger ($r = -0.1$, NS). Further, there were no interactions between BAS-d and hunger in predicting AB.

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[1] Because of the presence of neutral and buffer trials, food stimuli were presented somewhat less frequently than neutral stimuli. If differences in frequency were responsible for the increased AB to foods, we should see an overall bias for bland foods, which we did not. In addition, differences in frequency cannot explain relations between hunger and BAS-d and AB for food stimuli.

Table 1

Correlations Between the Two Predictor Variables (BAS Drive and Hunger) and Two Types of Attentional Bias (Overall Bias and Disengagement) for Bland and Appetizing Foods at Different Exposures, Together With the Difference Between These Correlations and the Comparison Correlations Displayed on the Far Left

Comparison correlation	BAS drive and disengagement		
BAS drive and disengagement, appetizing 100 ms $r = -.28$, $p < .01$, $n = 90$	Appetizing 500 ms $r = .09$, NS $t(89) = 2.32$, $p < .05$	Appetizing 2,000 ms $r = .06$, NS $t(89) = 2.19$, $p < .05$	Bland 100 ms $r = .06$, NS $t(88) = 2.48$, $p < .05$
	Hunger and overall bias		
Hunger and overall bias, appetizing 100 ms $r = .22$, $p < .05$, $n = 88$	Appetizing 500 ms $r = .08$, NS $t(87) = 0.91$, NS	Appetizing 2,000 ms $r = .09$ $t(85) = 0.90$, NS	Bland 100 ms $r = .24^*$, $p < .05$ $t(85) = 0.61$, NS
	Hunger and disengagement		
Hunger and disengagement, food 100 ms $r = -.25$, $p < .05$, $n = 89$	Food 500 ms $r = .18$, NS $t(88) = 2.79$, $p < .01$	Food 2,000 ms $-.09$, NS $t(87) = 1.46$, NS	—

* Differs from coefficient reported in the text because of reduced sample size.

Discussion

We used a modified visual probe task with food-cues to examine whether stimulus relevance, both in terms of current biological value and chronic hedonic/motivational goals, biases attention. This appears to be the case.

Hunger predicted AB to food-cues (appetizing and bland) at 100 ms cue-duration, but not 500 or 2,000 ms duration. Using a neutral-neutral pair control (Koster et al., 2004), we found that hunger impaired disengagement from food-cues. That this effect was not confined to appetizing foods is consistent with the increased organismic relevance of food per se when hungry.

Mogg et al. (1998) reported that hungry individuals showed an AB to food words at 500 ms exposure. However, they (also Placanica, Faunce, & Job, 2002) used a median-split design to designate "hungry" and "sated" individuals. Such designs can be statistically problematic since, for normally distributed scores, a substantial proportion that were once adjacent to one another will be assigned to different categories. This can lead to a number of problems including loss of measurement reliability, misestimation of effect size and the occurrence of spurious statistical significance (MacCallum et al., 2002). As such it is difficult to directly compare our results with those of Mogg et al. (1998). Additionally, their study did not distinguish between faster orienting and delayed disengagement. Thus, our study is the first demonstration of an influence of hunger on attentional disengagement from food. Studies of AB for smoking-cues using visual probe methodology have not consistently seen influences of smoking deprivation (Field, Mogg, & Bradley, 2004; also Stafford & Yeomans, 2005), so our results provide novel evidence that the value of stimuli, resulting from changes in physiological state, can influence allocation of attention to stimuli relevant to those needs. These findings support the Component Process Model (CPM; Sander, Grandjean, & Scherer, 2005), in which an early appraisal check (occurring ~90–300 ms poststimulus onset) determines whether a stimulus is relevant to current well-being, which in turn determines subsequent resource allocation. The amygdala may compute relevance (Sander, Grandjean, & Scherer, 2005), so it is notable that hunger increases amygdala response to food images (LaBar et al., 2001; Mohanty et al., 2008).

We also found an overall AB for appetizing foods. Notably, trait reward-drive predicted delayed disengagement from appetizing foods at 100 ms stimulus-durations. Unlike hunger, the influence of reward-drive was specific to appetizing foods, and was independent of hunger. Reward drive predicts anticipation of reward from eating (Franken & Muris, 2005), and sweet and fatty food preferences (Davis et al., 2007). The results again support the CPM model, in that chronic hedonic goals bias attentional allocation to relevant stimuli (appetizing foods; also Papies, Stroebe, & Aarts, 2008). A recent study (Brignell, Griffiths, Bradley, & Mogg, 2009) found that trait external eating, which is correlated with reward drive (Davis et al., 2007) significantly predicted AB to food images in a visual probe task, at 500 and 2,000 ms stimulus-durations. However, they did not examine shorter stimulus durations, and did not look specifically at appetizing versus bland foods. Nor did they examine whether bias resulted from faster orienting or delayed disengagement. Our study is thus the first to demonstrate that reward drive, rather than external eating[2] per se, influences attentional disengagement from appetizing food cues, and that this occurs at short stimulus exposures. Reward-drive also predicts amygdala reactivity to appetizing, not bland foods (Beaver et al., 2006), again consistent with CPM.

Reward sensitivity predicts increased BMI (Davis et al., 2007). Some research suggests that selective attention to drug-cues plays a role in mediating their impact on drug-seeking (e.g., Cox, Pothos, & Hosier, 2007). It is possible that AB

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[2] In the present study level of external eating, as assessed by the DEBQ (Van Strien, Frijters, Bergers, & Defares, 1986), showed no significant correlations with bias for appetizing foods at 100, 500, or 2,000 ms ($r = .05$, .04, .06, respectively).

mediates the link between reward sensitivity and increased BMI (Calitri, Pothos, Tapper, Brunstrom, & Rogers, in press; Castellanos et al., 2009).[3] Alternatively, AB may be driven by the appetitive value of the reward expectancy evoked by appetizing food images, and may not causally relate to the influence of food-cues on food intake (Hogarth, Dickinson, & Duka, 2009). Future research could fruitfully test between these hypotheses.

A few recent dot-probe studies also suggest that appetitive stimuli can bias attention. Kemps and Tiggerman (2009) found difficulties in disengaging attention from chocolate images in chocolate cravers. However, only one stimulus duration (500 ms) was assessed and the motivational state underpinning chocolate craving has both appetitive and aversive components (Rodríguez, Fernández, Cepeda-Benito, & Vila, 2005). Brosch, Sander, and Scherer (2007) found a greater AB to images of infants, relative to adults. The magnitude of the bias correlated with arousal ratings of the pictures; consistent with the notion (Lang, Bradley, & Cuthbert, 1997) that arousal is an indicator of relevance. However, personally relevant (own children) stimuli were not used. Maner, Gailliot, and DeWall (2007) found an AB to attractive female faces, which was more pronounced in sexually unrestricted men, but the design could not disentangle orienting from disengagement. Vogt, De Houwer, Koster, Van Damme, & Crombez, (2008) found delayed disengagement from highly arousing, pleasant images (erotica, exciting sports). However, this effect was significant when erotic images were removed, so it is possible that potential danger cues present in the sports pictures (sky diving, etc.), rather than appetitive arousal lead to increased attentional allocation.[4] Hence, our results provide some of the strongest support for the notion that relevance to *both* homeostatic needs *and* hedonic goals, regardless of valence, is a key determinant of attentional allocation.

Notably, hunger and reward drive led to delayed disengagement, not faster orienting at 100 ms, but not 500 or 2,000 ms stimulus durations. Anxiety research has found stronger effects on disengagement, suggested to result from alterations to specific subsystems within a serial model of attention (Derryberry & Reed, 2002; Fox, Russo, Bowles, & Dutton, 2001). Our results are however consistent with a relatively short-lived attentional process. Neurophysiological data reveal that, in contrast to serial models, attention is allocated to a new object before it disengages from the previously attended object (Khayat, Spekreijse, & Roelfsema, 2006): switching attention occurs via a fast target facilitation followed after ~60 ms by a suppression of responses to the object from which attention is removed. Delayed "disengagement" may thus result from such competitive interactions over a short temporal window of attention (Bundesen & Habekost, 2008), suggesting an integration of biased competition models of attention and appraisal models of emotion.

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[3] In the current study the range of BMI scores was restricted and there were small, but nonsignificant correlations, between BMI and reward drive ($r = .11$) and between BMI and attentional bias for appetizing foods at 100 ms ($r = .11$), 500 ms ($r = .10$) and at 2,000 ms ($r = .11$).

[4] In the present study, arousal ratings were collected for each of the food pictures used in the dot probe task. Although hunger showed a significant correlation with arousal for appetizing foods ($r = .24$, $p < .05$) there was no significant correlation between BAS-d and arousal for appetizing foods ($r = .02$), or between arousal and attentional bias for appetizing foods at 100 and 500 ms ($r = .14$ and .13, respectively). However, there was a significant correlation at 2,000 ms ($r = .21$, $p < .05$).

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