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Visual cues associated with sweet taste increase short-term eating and grab attention in healthy volunteers.

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Abstract

Most studies that examine responses to food cues use images of actual foods as stimuli. Since foods are rewarding in multiple ways, it then becomes difficult to try and partial out the role of the importance of different aspects of food reward. Here we aimed to evaluate the impact of novel visual cues specifically associated with the immediate sensory reward from a liked sweet taste. In the training phase, one visual cue (CSsweet) was associated with the experience of sweet taste (10% sucrose) and a second, control cue (CSneutral) with a neutral taste (artificial saliva) using a disguised training procedure. In Experiment 1, participants (n = 45) were given an ad libitum snack intake test 30 min post-training, either labelled with CSsweet or CSneutral. Total caloric consumption was significantly higher in the CSsweet (650 ± 47 kcal) than CSneutral (477 ± 45 kcal) condition, but ratings of liking for the snacks did not differ significantly between conditions. In Experiment 2, participants (n = 80) exhibited an overall attentional bias (22.1 ± 9.9 msec) for the CSsweet relative to CSneutral cue (assessed using a dot-probe task), however rated liking for the CSsweet did not change significantly after cue-sweet training. Likewise, measures of expected satiety for drinks labelled with CSsweet did not differ significantly from CSneutral. Overall these two experiments provide evidence that associations between neutral visual cues and the experience of a liked sweet taste leads to cue-potentiated eating in the presence of the CSsweet cue. With no evidence that cue-sweet training altered rated liking for the visual cues, and in keeping with extant literature on the dissociation of hedonic and rewarding properties of food rewards, we propose this potentiation effect to reflect increased incentive salience.

Key words

Taste hedonics, sweet, cue-potentiated eating, conditioning, incentive learning.
1.0 Introduction

Humans, like other animals, monitor their current and future state and environmental signals of resource availability or scarcity in a dynamic process that regulates appetite [1, 2]. The worldwide increase in obesity [3, 4], however, reflects how problematic the process of appetite control has become for humans living with an over-abundance of food in the context of reduced energetic needs [5, 6]. Amongst the many features of this “obesogenic” environment, the ubiquity of food-related cues has received particular attention as a potential driver of over-consumption [7-9]. In line with this, obese individuals are hyper-reactive to food cues [10]. This understanding has led to novel approaches to obesity treatment which focus on retraining individual responses to food cues [e.g. 11, 12]. However, further development of these approaches is hampered by our inadequate understanding of the complex associations between food cues and different aspects of the rewarding nature of eating.

The idea that food is rewarding, and that food-associated cues are endowed with rewarding properties to impact on a range of motivational processes, is critical to studies examining responses to food cues. But foods can serve as rewards in multiple ways, including as an immediate sensory experience (hedonic reward) and through the nutrients they provide. These two aspects of reward map onto current motivational models that dissociate hedonic, liking, from the incentive properties that mediate desire or wanting [13, 14]. However, what becomes difficult in studies which examine responses to images of foods is that these images are likely to involve associations with both liking and wanting. Moreover, the degree to which any individual responds to a given food image would depend on their past experience with that image and its associated food, which is outside of the control of the experimenter. Beyond these
primary reward-related associative memories, food images may also evoke broader memories, including of when and with whom specific foods were consumed, potentially health-related concerns, and so on. Thus, for example, an image of a chocolate cake may trigger expectations of liking, a desire to consume (wanting) and memories of special occasions or worries about weight-gain and ill-health. Moreover, some of these the consumer may be aware of, but other reward associations may be at an unconscious level [13]. The key issue is the lack of access the experimenter has to what has been learned previously for each person.

One possible solution is to train new associations explicitly targeted at specific aspects of food reward, and that is the approach taken here, focussing on the rewarding experience of a liked sweet taste as an example of hedonic reward. Previously we used an analogous approach where we associated novel visual cues with the experience of winning or losing food rewards [14]; notably, participants subsequently consumed more in a snack intake test when test foods were labelled with cues previously associated with winning food. However, in that study the training associated novel visual cues with the chance to work for pictures of snack food rewards. While that study provided evidence that cues associated with earning foods could themselves potentiate subsequent eating, it is not possible to determine what aspect of food reward drove these effects. Moreover, in that study the cue acted as a signal for when food could be earned, or said differently as an (instrumental) discriminative stimulus. However, studies in non-human animals have conceptualised and studied cue-potentiated eating in terms of explicit stimulus-stimulus-type Pavlovian associations [15, 16], and the present studies built on these, as well as our earlier paper, to focus on (a) Pavlovian associations and (b) one specific aspect of food reward.
Here we specifically target the hedonic reward of a specific sweet taste. One of the critical pieces of evidence used to develop the idea of wanting and liking as separable but interacting components of reward is the response to sweet tastes [17]. Critically, the positive orofacial reactions of rats experiencing a sweet taste were interpreted as evidence of the hedonic component of the neural basis of reward, and led to the discovery of discrete brain areas (“hedonic hotspots”) strongly activated by sweet tastes, and which were dissociable from areas associated with acquired incentive motivation [18, 19]. Given the importance of sweet taste, and the widespread belief that liking for sweetness is a driver of obesity [20], specifically, we examined whether cues explicitly associated with the brief experience of a liked sweet taste, relative to a neutral taste, would 1) alter subsequent snack intake (Experiment 1), and would 2) attract attention, increase liking and generate satiety expectations (Experiment 2).

The first issue addressed is the extent to which the presence of a sweet-associated cue modifies acute ingestion. The idea that the presence of extrinsic food-related cues in the environment may themselves lead to overconsumption has been widely supported by studies of cue-potentiated feeding in non-human animals [e.g. 15, 21, 22]. In those studies, novel cues (interpreted as Pavlovian conditioned stimuli, CS) were presented either during a meal (CS+) or between meals (CS-). Subsequent presentation of the CS+, but not CS-, to animals who were sated have been shown to both initiate feeding [16], and to increase meal-size [21, 23]. Likewise, re-exposing rats to an environmental context previously paired with food availability can re-initiate and potentiate feeding in sated rats; an effect dependent on activation of brain structures implicated in other forms of Pavlovian conditioning effects, such as the basolateral amygdala (Petrovich etc).
We are aware of only one paper in humans which has used an explicit cue-food training paradigm to explore similar cue-potentiated eating with extrinsic Pavlovian conditioned type cues [24]. In two experiments preschool children in the USA associated one stimulus (CS+: rotating red light plus music) with the availability of palatable snack foods (placed on the table adjacent to cue presentation), and a second CS- cue (a red, yellow and green traffic light and a distinctly different piece of music) when no food was present. In Experiment one, children ate 75 kcal more at a snack intake test when the CS+ was present than the CS-, and this effect was replicated in a second experiment where children again ate significantly more in the presence of the CS+ (190 kcal) than the CS- (118 kcal). Interestingly, all 15 children initiated eating within one second after CS+ presentation, compared to 3 out of 15 for the CS-, further illustrating the extent to which the potentiation effect is stimulus-bound. However, whether the association was driven through enhanced liking or wanting for the test foods is unclear, noting that these concepts have been developed since that study was conducted. Our own, previous study provided additional evidence from the laboratory that cues associated with receipt of food could potentiate subsequent snack intake [14], with the cues in that study acting as instrumental discriminative stimuli. Whether similar effects will be seen for Pavlovian associations of novel visual cues and a liked sensory experience (e.g. sweet taste) remains untested. Experiment 1 therefore examined the extent to which novel visual cues associated with the experience of a liked, sweet taste could alter voluntary intake of sweet and savoury snack foods, using a disguised intake test.

2.0 Experiment 1: Effects of Pavlovian cue-sweet associations on ad libitum intake of snack foods and hedonic ratings.
2.1 Methods

2.1.1 Design and ethics

The study used a between-participants design to contrast intake of, and liking for, four snack foods and two drinks labelled with visual cues which were trained to be specifically associated with either a liked, sweet taste (CSsweet condition) or a neutral taste (CSneutral condition). The study protocol was approved by the University of Sussex Science and Technology C-REC Ethics committee (protocol MYTRS1211), and was conducted in accordance with the ethical standards laid down by the British Psychological Society and in line with the Declaration of Helsinki.

2.1.2 Participants

Potential participants, largely students and staff at the University of Sussex, were notified of the study through postings on a recruitment webpage and posters placed around the campus. We excluded those who had ever been diagnosed with an eating disorder, were diabetic, had an allergy or aversion to any of the ingredients they might experience in the snack intake test, smoked more than five cigarettes per week or who were on prescription medication (excluding the contraceptive pill). Additionally, to control for potential confounding effects of dietary restraint, potential participants who scored greater than 7 on the Three Factor Eating questionnaire [TFEQ: 25] restraint scale were excluded since this could have affected intake.

A total of fifty healthy volunteers (25 women) were recruited and randomly assigned to either the Experimental or Control condition. Demographic data for the final sample
of 45, after exclusions (see 2.1.7), are shown in Table 1: there were no significant
differences in age, BMI, hunger at test or TFEQ restraint between the two test groups.

2.1.3 Sweet-liker screening.

The key association in this study was between a novel visual cue (CSsweet) and a liked
sweet taste (10% sucrose solution). There is clear evidence for significant individual
differences in hedonic response to sucrose in humans [26], and past research has shown
that these individual differences influence performance in tests of sucrose-based associative
learning [27, 28]. To ensure participants responded positively to the 10% sucrose solution,
all potential participants attended a short screening session at least one day before the
main test session during which they rated two samples of 10% sucrose solution and two
samples of water for pleasantness, sourness, sweetness, bitterness and saltiness using visual
analogue scales (VAS). The VAS were end-anchored with ‘Very pleasant’ (scored 100) and
‘Very unpleasant’ (scored 0) for rating flavour pleasantness, and ‘Extremely’ (scored 100)
and ‘Not at all’ (scored 0) for the other 4 ratings. The label for the dimension evaluated (i.e.
“How pleasant was the flavour?”) was presented above the centre of each line. Ratings
were made using Sussex Ingestive Pattern Monitoring software (SIPM, version 2.013 or
later, University of Sussex). Ten millilitre samples of each solution were refrigerated and
brought to room temperature prior to tasting. Participants progressed to the main testing
sessions only if their average rating of the two sucrose solutions was at least 55pt on both
the pleasantness and sweetness VAS: those who failed to meet these criteria were
excluded. In total, 78 participants were screened of whom 50 met the criteria to
participate. This procedure was based on previous studies of learning with sweet-taste
stimuli in this laboratory [27-29] and elsewhere [30, 31].
2.1.4 Cue-taste association task

The cue-taste associative learning task was modified from a procedure previously developed to pair odours and sweet tastes [27, 32], and used a ‘false odd-one-out’ method. The task commenced with instructions displayed on a computer screen and was programmed and controlled using E-Prime (version 1.2, Psychology Software Tools). In total, each participant experienced a total of 15 pairings of one cue paired with the sweet taste (CSsweet condition) and 15 pairings of a second cue paired with the neutral taste (CSneutral condition). This was achieved by the participants completing five blocks of five trials, with each block comprising one instance of the CSsweet, CSneutral and three filler trials. On each of these trials they tasted a set of three cups of stimuli. To disguise the cue-taste pairings, the experiment was presented to participants as an “odd-one-out” task, where on each trial they were asked to identify which one from each set of three stimuli differed in flavour. Crucially, during both the CSsweet and CSneutral trials there was no difference, forcing participants to pay close attention to those stimuli and to record a guess about which was different. The other three trials were fillers where there was a clear, unambiguous odd-one-out. The 15 test stimuli were presented as 150ml samples in 200ml polystyrene cups, with five rows (one row each for the two target and three distractor trials) of sets of three cups, on a large white tray. Only the relevant visual cue indicated which set of samples to taste on each trial. The positioning of the two target and three control rows was randomised between participants.

Participants received the following instructions:

“For this task, you will be presented with an odd-one-out test. You will be asked to take one of the sets of three drinks and place it in front of you. Your task will be to taste
each solution and determine which solution is the odd-one-out based on its taste. Some
trials will be hard and some will be easy. You must select the solution that you think is
the odd-one-out by its location on the tray. For example, if you think the solution on the left
of the tray is the odd-one-out then click the picture on the left of the screen.”

To ensure participants paid sufficient, close attention to the visual cue, the relevant cue
for each trial was displayed both on the computer screen and was printed onto each cup for
that set (as a 4cm x 4cm label). Each trial then started with the on-screen display of the
visual cue indicating which set of three stimuli were to be assessed. Beneath the on-screen
cue were three response boxes (green coloured rectangles) matching the position of each of
the three stimuli (left, centre, or right), and once participants had determined which was
the odd-one-out, they selected the relevant box. Participants were instructed to use the
visual cue to identify the relevant stimuli, to take a small sip from each cup (in whichever
order they liked), swirl then expectorate, and to rinse with water between each solution.
The order in which the five sets was displayed within each block was randomised, with a
10 second pause between trials, and a 30 second pause between each of the five blocks.
The visual cues were in the form of novel “logos” (Figure 1), selected from a series of
images originally designed by Kuwayama [33]. A pilot study was conducted to test ratings of
liking and familiarity for ten potential cues, and the five used here were on average rated as
neutral for liking (all scoring 40-60 on 100pt VAS liking scale), and as relatively unfamiliar (all
<40 on VAR familiarity rating). These cues have previously been used in other successful
studies of cue-based learning in a food context [14, 34].

Images were assigned to serve as either CSsweet, CSneutral, or one of the three control
images on filler trials, and this was counterbalanced across conditions.
On the two key picture-taste training trials in each block, the three solutions were identical (i.e. a false odd-one-out): one set had three cups of 10% sucrose labelled with the CSsweet cue, and the second set labelled with the CSneutral cue all contained a neutral taste, consisting of “artificial saliva” (1.87g/l of potassium chloride, KCl, Sigma-Aldrich, and 0.21g/l of sodium bicarbonate, NaHCO3, Sigma-Aldrich, dissolved in deionised water; [35]). The other trials were fillers, and for these there was a clear and obvious odd-one-out options. One of these trials had three cups of water flavoured with acai flavouring (Givaudan plc, UK), two with a weaker solution (0.10g/l), and one stronger (0.19 g/l); one trial consisted of two cups of grapefruit flavour (0.15g/l, Givaudan plc, UK) and one cup of water, and the final control trial consisted of one cup of raisin flavour (0.15g/l, Givaudan plc, UK) and two cups of water. The position of the correct answer on control trials was counterbalanced.

No data were recorded as the sole aim of the procedure was to co-present the relevant visual cue and taste solution.

2.1.5 Snack intake test

The effects of the Pavlovian learnt taste cues on subsequent food consumption were tested using a single snack intake test (Figure 2a), where participants were served a tray of four commonly consumed UK-based snack foods in white bowls, consisting of two sweet foods (chocolate chips, Cadbury’s UK and flapjack bites, Sainsbury’s UK) and two savoury foods (mini-cheddar biscuits, McVities UK and pretzels, Snyders UK), along with a glass of a sweet cordial (fruit concentrate, Robinson’s UK) and a glass of water. Depending on the condition, the food and drink containers were either all labelled with the CSsweet or CSneutral cue. Participants were told, using on-screen instructions
displayed using SIPM software, that they had 5 minutes to taste all of these items, that they would rate the products at the end of the task, and that since any leftovers would have to be disposed of, they were welcome to eat and drink as much as they liked. Performance during the taste test was monitored by continuous weighing of the tray of snacks (using a disguised digital balance, model Sartorius BP 4100-S, and SIPM software) and by video recording using a small web-cam (Logitech C170) attached to the top of the PC monitor, and angled down to capture the whole snack tray (data not reported here). At the end of the 5-minute ad-lib consumption test they were instructed to stop eating, and then rate how pleasant, sweet, salty, savoury and familiar each item was using 100pt VAS end anchored with “Not at all [descriptor]” and “Extremely [descriptor]”.

2.1.6 Procedure

All testing was conducted in small windowless air-conditioned test cubicles in the Sussex Ingestion Behaviour Unit at the University of Sussex. Having consented to participate and passed the sweet-taste screening, participants were invited to attend for a single session. To control appetitive state at testing, they were invited to attend the laboratory at a fixed time between 1200 and 1400h, where they were served a fixed lunch, consisting of a cheese and cucumber sandwich (40g of medium flavoured cheddar cheese, Sainsbury’s plc “Great Every day” brand, Kingsmill plc, UK), a 34.5g packet of crisps (ready salted, Walkers brand, PepsiCo UK), five cherry tomatoes and a glass of water (total energy 554kcal). Once consumed, they were allowed to leave the laboratory for 2h but were instructed to eat nothing and consume only water during this time. Testing started with a brief “mood and appetite” survey, consisting of target ratings of hunger, full and thirst, randomly mixed in with distractor mood questions of how calm, clear-headed, energetic, headachy and tired
they felt, all presented as 100pt VAS (question format “How [descriptor] do you feel right now?”, presented using SIPM software). This allowed us to test for spurious differences in baseline appetite between the CSsweet and CSneutral conditions.

Participants then completed the cue-taste association task, which took around 20 minutes. At the end of this task they completed a contingency awareness test, presented using E-Prime. Specifically, they were presented with all five logos, one at a time, and five boxes labelled with the taste names bitter, neutral, salty, sour and sweet, and were asked to select the taste that they most strongly associated with that logo. They then rested in a nearby waiting room for 30 minutes before returning to the test cubicle to complete the ad-lib snack-intake test. They then were given a structured debriefing, where they were first asked to state what they believed the purpose of the study was, and then explained the true aims of the study. Their age, height (m) and weight (kg) were recorded, and they were thanked and rewarded with either a £7 payment or course credits for completion of a required ‘research skills’ element of their undergraduate degree programme.

2.1.7 Data analysis

Although 50 participants were recruited, data for 5 participants had to be excluded for one of the following reasons. One participant was found, from the video analysis, to have removed some of the food but not consumed it, and one misunderstood the instructions and only took the minimum of each item needed to complete the ratings (all items less than 5g, participant identified as statistical outlier for overall energy intake). A system malfunction meant we lost all intake data for three participants.
Individual intake (g) of all six items in the snack intake test was calculated and converted to total energy consumed. These values were then summed to give three key measures for statistical analysis of the intake results: total energy consumed (kcal), total sweet energy consumed (the sum of energy from the two sweet foods and the cordial) and total savoury energy consumed (sum of the two savoury foods). Overall intake was contrasted between cue conditions (CSsweet or CSneutral) while controlling for sex (man or woman) using univariate Analysis of Variance (ANOVA), both with and without inclusion of rated hunger as a covariate. Whether effects of the cues depended on the nature of the food items was tested by contrasting food type (sweet or savoury, within participant) between cue conditions, again controlling for sex and hunger, using repeated measures ANOVA. To test whether awareness of the contingent relationship between the trained cue and associated target sweet taste affected the impact of cue on intake, those who correctly selected sweet taste in the contingency awareness task were defined as aware, and those who chose one of the other 4 options as unaware. Additional ANOVAs with cue condition and awareness as factors re-tested the overall and food specific effects of training. Effects of cue training on liking for the 6 test products were determined by analysis of the VAS rating for how pleasant each of these items tasted, taken at the end of the snack intake test. These were contrasted between cue-conditions, with item and sex as additional factors using a mixed ANOVA.

Potential confounding differences in age, BMI and hunger at test were assessed with t-tests (see Table 1): none of these contrasts were significant and so these variables were not included as covariates in the main analyses. All analyses were conducted using SPSS version 25.0 run on Macintosh computers.
Data have been deposited at the University of Sussex Data Repository (Figshare) and will be made available on acceptance\(^1\).

\(^1\) URL for use in review: [https://figshare.com/s/c9b3d2bab98b24768665](https://figshare.com/s/c9b3d2bab98b24768665)

### 2.2 Results

#### 2.2.1 Snack food intake

Overall caloric intake at the snack test was significantly higher in the CSsweet than CSneutral condition \([F(1,41) = 7.07, p=0.011, \eta^2 = 0.15]\): as expected, men consumed on average more \((650 \pm 47\) kcal) than did women \((477 \pm 46\) kcal): \([F(1,41) = 9.62, p<0.001, \eta^2 = 0.19]\), but the interaction between condition and sex was not significant \([F(1,41) = 0.01, p = 0.99, \eta^2 = 0.01]\), showing similar effects of the cue-based associations across sexes (Table 2). We also explored whether the training specifically increased intake of sweet relative to savoury foods by contrasting caloric intake from the two savoury and two sweet-snack foods across conditions. Overall, participants consumed more energy as sweet than savoury snacks \([F(1,41) = 130.53, p<0.001, \eta^2 = 0.76]\), with the interaction between cue and snack type only approaching significance \([F(1,41) = 3.20, p=0.072, \eta^2 = 0.07]\). We saw increased intake of both snack types when labelled with the CSsweet cue, versus neutral (Figure 2b).

We also explored the extent to which explicit awareness of the CS-taste associations might have affected behaviour in the snack test. Those who selected sweet as the taste for the image which had actually been paired with the sweet taste were considered to be aware of that contingent association: on this basis, 21 participants were defined as
contingency-aware, and 24 as unaware. Re-analysis of overall energy intake including
contingency awareness as a factor confirmed significantly higher intake after the CSsweet
than CSneutral F(1,41) = 5.55, p = 0.023, η² = 0.12], and but found no significant main
effect of CSawareness (F(1,41) = 0.07, p=0.79, η² = 0.01) or awareness x CS interaction
effect (F(1,41) = 0.42, p = 0.52, η² = 0.01). When controlling for awareness, the interaction
between CS and food type (sweet or savoury) again only approached significance [F(1,41 =
3.54, p=0.067, η² = 0.08], but the contrast of CSsweet versus CSneutral was significant for
sweet [F(1,41 = 5.64, p=0.022, η² = 0.12] but not savoury [F(1,41 = 2.48, p=0.12, η² = 0.06]
foods. These data suggest that the differences in intake between the CSsweet and
CSneutral conditions were unlikely to be driven by demand effects arising from explicit
awareness of the cue-taste associations.

2.2.2 Rated liking and perception of the test snacks
At the end of the intake test, participants completed the Visual analogue Scale (VAS)
ratings of the hedonic and sensory characteristics of all six items from the ad libitum intake
test. We anticipated that the presence of the CSsweet cue might enhance liking, particularly
for the sweeter items, and might also lead to enhanced sweetness ratings. However, there
was no significant effect of cue [F(1, 48)= 2.29, p = 0.14, η² =0.07], and no significant
interaction between condition and food type, [F(5, 240)= .33, p = 0.90, η² =0.02], for the key
rating of how pleasant each item tasted. As expected, there was a significant difference in
rated pleasantness of the different items [F(5, 240) = 11.93, p < .001, η² = 0.20], with
chocolate the most (89 ± 2) and water the least liked (62 ± 4). Likewise, analyses of the
rated sweetness of the six items found no evidence that this was affected by the CS type
[F(1, 48) = 0.17, p = 0.68, η² = 0.03]. Thus, contrary to our expectations, there was no
evidence that the sweet-associated cue altered the perceived hedonic or sensory
characteristics of these snacks.

2.3 Discussion

The data from Experiment 1 provide evidence that the presence of a cue which had
been briefly associated with the experience of a liked sweet taste can potentiate ad lib
snack food intake. This extends the previous literature showing that a food-availability
cue increased intake [24], by showing that a cue associated with the oral experience of a
liked sweet taste (without ingestion) increased intake compared to a cue associated with
a neutral taste; and our results provides further translational evidence from animal
studies. The increase in intake also tended (but only approached significance) to be
greater for the taste the cue had been associated with; i.e. the sweet-paired cue
significantly increased intake of sweet items, even more clearly when contingency
awareness was controlled for. This is in keeping with previous research in non-human
animals that have shown cue-specificity in cue-potentiated feeding [22]. There was also
evidence that this finding was not simply a demand effect of the study design since
similar increases in intake were seen in those who could explicitly recall sweet as the
taste associated with the CSsweet (classified as aware) as well as those who could not
(classified as unaware).

Experiment 1 provides evidence that a sweet-associated cue can increase intake, but
how these cues enhanced intake is still unclear. There was no evidence that the
presence of the cue increased liking for the snack foods, suggesting that any potential
increase in liking for CSsweet through evaluative conditioning did not in turn affect liking
for the foods being consumed during the test. However, we did not directly test whether
liking for the CSsweet cue was altered as a function of cue-taste training, as might be expected from evaluative conditioning [36], so this was tested in Experiment 2. It could also be that the CSsweet cue acquired greater salience, and if so, it might attract greater attention from consumers which in turn would facilitate any intake effect; that is, incentive salience theory posits that cues which predict reward acquire, among other qualities, the ability to attract greater attention [37]. Therefore, in Experiment 2 we also explored whether brief cue-sweet associations increased attention to the CSsweet, using a dot-probe visual attention task. A third possibility might be that the brief experience of a sweet taste evoked memories of sweet-associated foods, and those explicit memories somehow impacted subsequent snack intake. For instance, when food-related memories are recalled, they evoke expectations about the likely impact of ingestion on appetite, often referred to as satiety expectations [38]. We therefore tested to see whether the cue-taste association task altered satiety expectations for the sweet-paired cue.

3.0 Experiment 2: Effects of cue-sweet associations on cue-liking, attentional bias and satiety expectations.

3.1 Method

3.1.1 Design and Ethics

The study used a within-participants design to compare attentional-bias toward, and rated liking and expected satiety for, visual cues which were trained to be specifically associated with either a liked, sweet taste (CSsweet condition) or a neutral taste (CSneutral.
The study protocol was approved by the University of Sussex Science and Technology C-REC Ethics committee (protocol ER/Martin/7).

### 3.1.2 Participants

Eighty healthy volunteers (58 women), participated. Recruitment was the same as for Experiment 1 except that the exclusion based on food allergies and aversions to the snack foods was dropped since no food was consumed. Instead of pre-screening for restraint using the TFEQ as in Experiment 1, the TFEQ was administered at the end of testing and restraint included in analyses as a covariate. Demographic data are shown in Table 3: in this sample the women were slightly more restrained than men, and men had higher average BMI than did women. In total 125 potential volunteers were screened for sweet-liking: the final sample of 80 met the sweet-liking criteria used in Experiment 1.

### 3.1.3 Cue-sweet training

The cue-sweet training was identical to Experiment 1 except that only two filler trials were used because the study included rated liking for the five logos, and we needed one cue to be unexposed between liking ratings to test for potential confounding effects of exposure/familiarity on liking [39, 40]. The two filler trials used two cups of water with added chai flavour (0.1g/l; International Flavours and Fragrances, UK) and one cup containing water with added cranberry flavour (Firmenich, Switzerland), the second with two cups of weak saline solution (0.1g/l NaCl), and a third with water.

### 3.1.4 Attentional bias measure
Attentional bias to the visual cues was assessed using a dot-probe test. Originally developed as a test of attention in relation to threat cues [see 41, 42], and then adapted to explore food-related attentional biases [e.g. 43, 44, 45], the theory for this test is that if attention is drawn to a particular image, and the subsequent visual probe (*) then appears at the same location (i.e. visual probe and target image locations are congruent), response time will be faster than on those occasions when the probe and image are at opposite locations (i.e. locations are incongruent).

The procedure for the dot-probe task (Figure 3) was modelled closely on versions used previously in our laboratory [46] and elsewhere [e.g. 44, 47, 48], and was presented on 15” monitors attached to a Windows PC computer, programmed using E-Prime 1.2 software. The task consisted of 120 discrete trials, each consisting of a variable inter-trial interval (varying randomly between 100 and 700 msec), a brief display of a central fixation point (100 msec), and then the display of two of the cues used in the cue-taste association task for 500 msec; one positioned on the left and one on the right of the display screen. After cue display, and on 33% of trials, a target visual probe (an asterisk, “*”) was displayed at one of the two picture locations; the participant’s task was to respond as quickly and accurately as possible whenever they detected a “*” by pressing the keyboard spacebar. Picture location was not a predictor of the position of the visual probe. Visual probes were displayed either until the participant responded or for a maximum of 1250msec. On non-probe trials the screen remained blank for 1250msec. All possible combinations of the five trained cues were displayed, with every cue presented an equal number of times on the left and right side of the screen, giving 40 combinations for all cues and locations for the visual-probe trials, which were interspersed with 80 trials where no probe was presented. The critical data were reaction times on dot-probe trials depending on the image displayed, the
side the image was displayed on, and the position of the dot-probe relative to the cues of interest (those trained as CSsweet and CSneutral for each individual). The dot-probe procedure lasted between 5 and 6 minutes.

3.1.5 Liking for the trained cues

To assess changes in liking for the test cues as a function of conditioning, liking ratings were made both before and after training using 100pt VAS, end-anchored with “Dislike extremely” and “Like extremely”, with the question “How much do you like this image?” positioned above the scale, programmed using E-Prime 1.2 software. These ratings were taken before and after the disguised cue-taste association task. Pre-training, participants were presented with the five cues used in the cue-taste association task (Figure 1), plus four distractor, general non-food images included to further disguise the study aims (e.g. pictures of flowers, stationary). Each image remained onscreen until the rating had been indicated, and the nine images were presented in random order. After training only the five images from the cue-taste association task were rated, again in random order and using the same rating scale.

3.1.6 Satiety expectations

To assess whether cue-taste associations altered satiety expectations, participants were presented with two 200 ml sample drinks. One (sample A) was a clear unthickened solution (Aloe Vera juice original, OKF plc, Korea); the second (sample B) was an opaque, thicker solution (banana milkshake, Frijj brand, Muller plc UK), which we predicted based on previous work [49] would generate stronger satiety expectations. Participants were instructed, using a procedure programmed using E-Prime 1.2 software, to look at the two
bottles, but not to open or drink the contents. For each of the five cues used during the
cue-taste training phase, and an additional trial with no visual cue, they completed two
ratings. Initially, for the five cues they were instructed to “Imagine drinking all of Bottle
[A/B] labelled with:”, with an image (8cm x 8cm) of the relevant cue displayed on-screen
below: for the unlabelled trial they were simply asked to “Imagine drinking all of Bottle
[A/B]”. The first rating, measuring expected satiation, asked “How full would you expect to
feel immediately after consuming product [A/B] when labelled with this picture?”, and the
second (expected satiety) asked “How hungry would you expect to feel one hour after
consuming product [A/B] when labelled with this picture?”. The order in which these six
trials was presented was fully randomised. This method has been used previously in our
laboratory to successfully discriminate actual differences in expectations between known
products [50], and to detect changes in expectations for odour stimuli previously associated
with the experience of orosensory texture [51].

3.1.7 Procedure

Testing was again conducted in small, windowless air-conditioned test cubicles in the
Sussex Ingestive Behaviour Unit at the University of Sussex, between 1000-1200h and 1500-
1700h, avoiding main meal times. Potential participants were told they were taking part in
a study examining the effects of reward on cognitive performance in order to give a
plausible account of the study without revealing the specific aims. Participants who met the
inclusion/exclusion criteria were required to refrain from eating and drinking for the hour
prior to testing. On arrival they completed the same set of mood and appetite ratings as in
Experiment 1, in order to assess baseline hunger for inclusion in analysis, followed by the
baseline image liking ratings. They then completed the cue-taste association task. After a
10 min break they completed the three key test measures. Half completed the dot-probe attention task, followed by a 5 min break, and then post-training rated liking for the trained cues, and the test of satiety expectations. The other half completed the two sets of ratings first, then a 5 min break followed by the dot-probe task. The cue-taste awareness task used in Experiment 1 was not included since conducting that after testing could have interfered with responses on the attentional bias task. On completion of all three tasks, participants completed the TFEQ online using Bristol Online Survey software, and their age, height (m) and weight (kg) and sex were recorded. They were thanked for their participation and given the opportunity to have their names included in a prize draw (with £25 prize).

3.1.8 Data analysis

Three types of data were extracted to explore the outcome of Experiment 2: Reaction times (in msec) to the visual probe stimuli in the visual-probe task, and the 100pt VAS pleasantness and satiety expectation ratings. For the dot-probe task, the system failed for one participant and analyses were based on the remaining 79. We had full data for all 80 participants for all other measures. Raw datafiles included response data (reaction times) on every trial from the dot-probe task. For analysis, we extracted only those trials where one of the cues preceding each visual probe was the cue associated with the sweet taste (CSsweet) for each participant. For the key contrast of responses when CSsweet and CSneutral cues were co-presented, this yielded four trials, depending on the presentation of the cues (CSsweet on left or right of the screen) and whether the visual probe then appeared on the same side (congruent trials) or the opposite side (incongruent trials). To test whether brief cue-sweet training generated a bias for the
CSsweet cues, we conducted two analyses: The first contrasted reaction times when the cues displayed were the two trained stimuli (CSsweet and CSneutral), comparing trials where the visual probe and CSsweet were in the same location (congruent trials) or opposite locations (incongruent trials), while controlling for whether the CSsweet was on the left or right side of the screen (all within-participants), and including participant sex (between participants) using mixed ANOVAs. Overall bias scores were calculated as the average difference in reaction time between congruent and incongruent trials for both left and right-side CSsweet presentations. The same analysis approach was then repeated but comparing CSsweet against the three filler cues.

For liking ratings, the focus was on whether cue-taste training altered liking for the images, and this was determined by deducting the pre-training rating from that post-training, and contrasting these change data using ANOVAs. Expected satiation and satiety ratings were also contrasted using ANOVA between the CSsweet, CSneutral, control and unlabelled conditions, including the drink sample being evaluated as a control measure to test the sensitivity of these ratings to factors predicted to impact satiety expectations.

There were several factors that could have influenced outcomes: hunger at test, TFEQ restraint and participant age and BMI. Initial ANOVAs therefore including each of these as covariates. For attentional bias there were theoretical reasons why both hunger at test and restrained eating could predict bias for a sweet-associated cue and we report these analyses in full; but since in no analysis was age, BMI or restraint a significant covariate, we only report analyses with covariates where these were theoretically important. All analyses were again conducted using SPSS version 25.0 run on Macintosh computers: data are available online in the same file as Experiment 1.
3.2 Results

3.2.1 Attentional-bias for sweet-associated visual cues

Analyses confirmed that reaction time was significantly faster on congruent than incongruent trials $[F(1,78) = 4.98, p=0.029, \eta^2 = 0.06$: Figure 4a, left panel], indicating an attentional bias for the CSsweet. The overall difference in reaction times between congruent and incongruent trials (the bias score) contrasting CSsweet and CSneutral was $22.1 \pm 9.9$ msec; a bias similar in magnitude with biases reported in some studies using actual food images [e.g. 43, 52]. One potential issue of contrasting CSsweet and CSneutral trials is that this could be interpreted either as a tendency to look at CSsweet, or to avoid CSneutral images. We therefore also contrasted reaction time data when the CSsweet was displayed alongside the cues from the three control trials, two where there was no consistent cue-taste association and one which was not used in the cue-taste association task. Contrasts of trials where CSsweet was paired with these three cues also found a significant effect of whether the location of the visual probe was congruent or incongruent with the CSsweet image $[F(1,78 = 13.14, p<0.001, \eta^2 = 0.14]$, with faster reaction times when CSsweet and the visual probe were in the same location (Figure 4a, right panel). The overall bias for sweet-paired relative to these control cues was $24.5 \pm 7.1$ msec.

Because appetitive state [53] and dietary restraint may also predict bias for food-related cues (e.g. [54-56], but see [57-59]), we tested whether the bias for CSsweet was related to hunger and/or restraint, and whether this differed between sexes. For both the bias based on CSsweet relative to CSneutral and the control cues, there was no
significant differences in bias depending on sex ([F(1,75) = 0.19, p = 0.67, η² = 0.002] and [F(1,75) = 0.37, p = 0.55, η² = 0.005]), and bias scores were not affected by restraint biases were affected by how hungry participants were when tested for the CSsweet-CSneutral contrast ([F(1,75) = 5.44, p = 0.022, η² = 0.068] and also approached significance for the CSsweet-control contrast [F(1,75) = 3.77, p = 0.056, η² = 0.048]).

3.2.2 Liking for sweet-associated cues

To test the hypothesis that brief paired co-experience of the novel visual cues and the liked sweet taste would alter liking for the CSsweet cue, we contrasted liking ratings between cue conditions. We calculated overall changes in liking for each cue condition, and contrasted these changes between CSsweet and CSneutral cues, as well as the average for the three control cues. Change in liking did not vary significantly between conditions [F(2,152) = 1.84, p=0.16, η² = 0.024], with minimal changes in liking in all three conditions (Figure 4b). The timing of the post-training liking rating was counterbalanced so that half completed this before the visual-probe task and half afterwards, and this could potentially have led to extinction of any associated liking change in those who had repeated cue-exposure during the visual attention task. However, analysis of the effect of timing of ratings found neither a significant effect of timing overall [F(1,76) = 0.65, p=0.40, η² = 0.008] nor significant interactions between timing and cue-type [F(2,152) = 1.09, p=0.34, η² = 0.014], and there was no evidence of greater liking if tested immediately after training rather than after the additional cue-exposure from the dot-probe task. Addition of TFEQ-restraint did not alter the outcome, and neither restraint nor rated hunger were significant covariates in these analyses (largest F = 0.58, all ps > 0.56).
Finally, we explored whether cue-taste training resulted in changes in satiety expectations associated with each cue. As we learn about the foods and drinks we consume, we develop expectations about the impact ingestion will have on our motivation, both in relation to hunger and thirst [38, 60, 61]. As a sweet-taste might be experienced as an indicator that a product may contain energy [62], and so could have a greater impact on satiety once ingested, we reasoned that the CSsweet cue might similarly impacts satiety expectations after training. We therefore contrasted measures of expected satiety and satiation between the CSsweet, CSneutral, untrained and no-cue conditions (Table 4). As predicted, both expected satiation \( F(1,234) = 43.21, p<0.001, \eta^2 = 0.36 \) and expected satiety \( F(1,234) = 46.76, p<0.001, \eta^2 = 0.38 \) were greater for the thicker than thinner sample, confirming the test sensitivity, but there were no significant overall effects of cue on either measure (expected satiation: \( F(3,234) = 1.68, p = 0.17, \eta^2 = 0.02 \); expected satiety \( F(3,234) = 0.03, p = 0.99, \eta^2 < 0.001 \)), nor were any interactions involving cue significant. Overall these data provided no clear evidence that the CSsweet affected satiety-related expectations. Further analyses including sex, hunger and restraint did not alter the overall outcome, and none of these factors or interactions with these factors were significant (largest \( F = 1.88, \text{ all } p > 0.18 \)).

### 3.3 Discussion

Experiment 2 provided clear evidence that brief disguised pairings of novel visual cues alongside a liked sweet taste resulted in increased attention drawn by the CSsweet cue. These changes in attentional bias were measured in absence of reliable changes in liking
for the cue or in expectations about how products labelled with that cue might impact
satiety. For the liking ratings, it might have been expected that delaying these ratings
until after the dot-probe task could have diminished the effects of cue-taste training on
liking, but there was no evidence that this was the case; and indeed the wider literature
would suggest that evaluative changes like those looked for here would be relatively
resistant to extinction [63]. Furthermore, unlike in Experiment 1 where we pre-selected
participants to be unrestrained eaters, in Experiment 2, to simplify participant recruitment,
we did not pre-screen for restraint but instead included TFEQ restraint as a covariate in
analyses, and notably this was not significant for any of the three test measures. Likewise,
whereas Experiment 1 reported larger food intake by men than women (as expected), we
found no effects of sex on any of the measures in Experiment 2. These data provide clear
evidence that cue-sweet associations lead to enhanced attention for sweet-paired cues.
Moreover, the finding that hunger at test predicted attentional bias to the CSsweet cue is in
accord with a recent meta-analysis that found similar effects of hunger across a wide range
of studies using images of food [53].

4.0 General discussion

The data presented in this paper provide evidence that a few pairings of the visual cue
with the experience between novel, neutral visual cues and the experience of a liked sweet
taste increase snack intake for foods labelled with the CSsweet cue (Experiment 1) and
increase attention to the cue (Experiment 2). These findings illustrate that how visual cues
that are experienced alongside an enjoyable orosensory reward are likely to contribute to
short-term overconsumption, further validating previous research in non-human animals
[e.g. 21, 22, 23]. These data shed further light onto the potential role of food cues in overeating and (potentially contributing to) obesity.

Experiment 2 explored three different potential explanations for the increased food intake seen in Experiment 1. The simplest of these might have been that evaluative conditioning (EC) would lead to hedonic transfer from the liked sweet taste to the paired CSsweet cue [64]. The presence of that liked cue could then in turn increase liking for the snack foods, which in turn might increase intake [65]. In support of this theoretical position, there is both clear evidence that contextual information, such as implicit or explicit descriptions of food quality, can increase liking for foods [e.g. 66, 67], and some evidence that rated liking for visual cues can be modulate by pairing with tastes [68, 69]. However, there was no evidence for this from the present studies: in Experiment 1, the snack foods were not rated as more liked by those consuming them when labelled with CSsweet versus the CSneutral, and in Experiment 2, there was no evidence of altered liking for the actual CSsweet cue post-training. These findings appear to be inconsistent with the wider EC literature [70], though there have been relatively few published studies which have reported increased liking for visual cues associated with tastes, with the majority of taste-based EC studies using odours as CS [e.g. 27, 71]. Indeed, where both visual and orosensory stimuli were tested, there was evidence in changes in liking for the flavour but not colour of the taste-paired cues [72, 73]. It is also notable that the largest changes in liking occurred as an acquired dislike for stimuli paired with a aversive taste [73, 74]. The lack of evidence for increased liking for the CSsweet cues here however does not exclude liking as a potential mechanism, but at least in the present studies we find no support for that hypothesis as a major driver of increased intake.
Conversely, our attentional-bias data in Experiment 2 could be interpreted as evidence for increased incentive salience for sweet-paired cues, particularly since attentional bias has been widely used as evidence for increased incentive salience of reward-associated cues, including drug-associated cues [see 75]. That the relative brief co-experience of the images with the experience of a sweet taste without ingestion led to this bias was perhaps surprising, and warrants further investigation. Attention to the CSsweet cue also depended on how hungry participants were during training/conditioning, and this adds further evidence that hunger predicts attention to food cues [53]. Likewise, the lack of evidence for dietary restraint affecting attention to CSsweet is in line with the majority of studies which have explored these biases based on food images [e.g. 57, 59, 76] (cf [54]).

Our attentional measure was however relatively unsophisticated, and further research either using eye-tracking and/or more dynamic analysis of responses in the dot-probe task [e.g. 77] are needed to fully understand the nature of the altered attention to sweet-paired cues.

Given that the studies in this report set out to test the effects of simple sensory, hedonic associations between novel visual cues and a liked sweet taste, it is surprising that the outcome points more to an incentive rather than hedonic driver of subsequent performance. However, evidence that sweet liking predicts wider overconsumption is limited [78], and although the specific sweet taste stimulus used in these experiments was selected to be liked by these participants, the experience of sweet taste might also evoke wider appetite-related memories. For that reason we included the tests of expected satiation and satiety, where we found no significant effect of the presence of the sweet cue on these expectations. This prompts us to hypothesise that the incentive effects evidenced by attentional bias were not driven by expectations that the CSsweet cue would increase
Further research is needed to further test this hypothesis and to elucidate how brief cue-sweet associations result in increased attention to enhance or potentiate snack intake.

The current studies were conducted in healthy-weight young adults. It would now be interesting to test whether the same is seen, or indeed may be exacerbated, in overweight and obese populations, particularly since food-cue reactivity is seen as an important component of the obesogenic environment [7-9]. Although we did not specifically exclude overweight or obese individuals, only three participants (two in Experiment 1, one in Experiment 2) had BMI greater than 30, while 19 (8 in Experiment 1, 11 Experiment 2) had BMI in the overweight range (i.e. between 25 and 30). Exploratory correlations between BMI and intake in the CSsweet condition from Experiment 1 (r(26) = -0.15, p=0.45) and the attentional bias score from Experiment 2 (r(79) = 0.09, p=0.41) did not suggest stronger responses in overweight/obese participants, but the low frequency of overweight and obesity in our samples does not provide a strong test of potential greater sensitivity as a function of body weight.

As we were interested in responses to a liked sweet taste, we pre-screened participants to ensure that they would like the trained 0.29M (10%) sucrose solution, based on the approach used in our earlier work on odour-taste learning [27]. However, while the screening test we used was adequate to ensure participants met the study objectives, we (now) recognise that the concentration of sucrose we used would not have accurately identified the specific sweet-liking phenotype of our participants. In brief, more recent research clearly suggests that human adults display one of three distinct hedonic responses to sucrose [26, 79, 80]. Sweet dislikers show a clear aversion to concentrations above 0.1M, and our screening task should therefore have excluded
that phenotype. However, sweet likers fall into two distinct groups; extreme sweet likers who show increased liking with increasing sucrose concentration, and moderate sweet likers whose liking peaks at around 0.3 M [see 26]. Thus, we probably tested a mixture of extreme and moderate sweet likers in these studies, and follow-up studies might want to separate those groups to see if the same incentive effects are evidenced equally in both groups.

The success of these studies also depended on the effectiveness of the cue-taste training paradigm we used. The results suggest that the procedure we used did successfully form cue-taste associations, but in order to disguise the trained associations we were not able to specifically confirm the relevant timings of when each pairing of cue and taste were experienced. Future studies, perhaps using eye-tracking, are needed to better assess the actual temporal patterns of cue-taste pairings, for example testing whether those participants who had minimal delays between viewing the cues and experiencing the tastes show stronger associations.

In summary, the present paper provides evidence that the presence of visual cues that have been selectively associated with a liked, appetitive sweet taste can potentiate consumption of snack foods (Experiment 1), and at the same time attract attention (Experiment 2). Such simple hedonic associations may do likewise in the context of cues such as branding and other food-associated cues.
5.0 Acknowledgments

TRS doctoral studentship was funded by the UK Biotechnology and Biosciences Research Council (BBSRC). We would like to thank two undergraduate students, Ruth Horne and Olivia Churchwood, who assisted with data collection for Experiment 2.
6.0 References cited


Table 1: Demographic data for the two test conditions in Experiment 1. Data are mean ± SE.

<table>
<thead>
<tr>
<th>Measure</th>
<th>Experimental group (n=22)</th>
<th>Control group (n=23)</th>
<th>t-test</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age</td>
<td>22.0 ± 0.7</td>
<td>22.0 ± 0.9</td>
<td>t(43) = 0.12, NS</td>
</tr>
<tr>
<td>BMI</td>
<td>23.5 ± 0.5</td>
<td>23.0 ± 0.6</td>
<td>t(43) = 0.54, NS</td>
</tr>
<tr>
<td>Rated hunger</td>
<td>50.4 ± 5.8</td>
<td>47.6 ± 5.0</td>
<td>t(43) = 0.37, NS</td>
</tr>
<tr>
<td>TFEQ restraint</td>
<td>3.1 ± 0.3</td>
<td>2.7 ± 0.4</td>
<td>t(43) = 1.05, NS</td>
</tr>
<tr>
<td>Numbers of women/men</td>
<td>12/10</td>
<td>13/10</td>
<td></td>
</tr>
</tbody>
</table>
Table 2: Effects of the presence of cues previously associated with sweet (Experimental condition) and neutral (Control condition) tastes on total snack food intake (kcal), broken down by participant sex. Data are estimated marginal means ± SE.

<table>
<thead>
<tr>
<th></th>
<th>Experimental</th>
<th>Control</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Men (n = 20)</strong></td>
<td>751 ± 69</td>
<td>579 ± 69</td>
</tr>
<tr>
<td><strong>Women (n = 25)</strong></td>
<td>549 ± 63</td>
<td>375 ± 60</td>
</tr>
<tr>
<td><strong>Combined sample (n = 45)</strong></td>
<td>650 ± 47</td>
<td>477 ± 45</td>
</tr>
</tbody>
</table>
Table 3: Demographic data from Experiment 2

<table>
<thead>
<tr>
<th>Measure</th>
<th>Women (n=58)</th>
<th>Men (n=22)</th>
<th>t-test</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age</td>
<td>21.6 ± 0.7</td>
<td>21.9 ± 0.4</td>
<td>t(78) = 0.53, NS</td>
</tr>
<tr>
<td>BMI</td>
<td>22.2 ± 0.3</td>
<td>23.5 ± 0.5</td>
<td>t(78) = 2.13, p = 0.036</td>
</tr>
<tr>
<td>Rated hunger</td>
<td>42.5 ± 3.7</td>
<td>43.0 ± 5.7</td>
<td>t(78) = 0.08, NS</td>
</tr>
<tr>
<td>TFEQ restraint</td>
<td>8.6 ± 0.8</td>
<td>5.7 ± 4.7</td>
<td>t(78) = 2.13, p = 0.024</td>
</tr>
</tbody>
</table>
Table 4: Rated expected satiation and satiety for two drinks varying in thickness (A, thicker and B, thinner) depending on the associated image: either the image trained with a sweet taste (CSsweet), neural taste (CSneutral), the average across the 2 untrained images and no image. All data are estimated marginal means ± SE.

<table>
<thead>
<tr>
<th>Label condition</th>
<th>CSsweet</th>
<th>CSneutral</th>
<th>Untrained image</th>
<th>No image</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Expected satiation¹</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Drink A</td>
<td>51.4 ± 2.3</td>
<td>50.2 ± 2.3</td>
<td>48.2 ± 1.6</td>
<td>46.8 ± 2.2</td>
</tr>
<tr>
<td>Drink B</td>
<td>65.1 ± 2.5</td>
<td>64.2 ± 2.5</td>
<td>60.4 ± 2.0</td>
<td>62.4 ± 2.7</td>
</tr>
<tr>
<td>All</td>
<td>58.2 ± 2.0</td>
<td>57.2 ± 1.9</td>
<td>54.2 ± 1.3</td>
<td>54.7 ± 1.8</td>
</tr>
<tr>
<td><strong>Expected satiety²</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Drink A</td>
<td>56.1 ± 2.2</td>
<td>54.0 ± 2.3</td>
<td>54.9 ± 1.6</td>
<td>54.9 ± 2.2</td>
</tr>
<tr>
<td>Drink B</td>
<td>41.7 ± 2.1</td>
<td>43.3 ± 2.5</td>
<td>42.2 ± 1.6</td>
<td>43.1 ± 2.4</td>
</tr>
<tr>
<td>All</td>
<td>48.9 ± 1.7</td>
<td>48.6 ± 1.8</td>
<td>48.6 ± 1.3</td>
<td>49.0 ± 1.7</td>
</tr>
</tbody>
</table>

1. How full would you expect to feel immediately after consuming this drink?
2. How hungry would you expect to feel one hour after consuming this drink?
Figure Legends

Figure 1. The five novel logos used as conditioned stimuli in all three experiments.

Figure 2. Intake in the snack test from Experiment 1: A) image showing the layout and positioning of the CS images, B) overall caloric intake, showing intake of both sweet and savoury items for snacks labelled with either the CSsweet or CSneutral cues. Data are mean ± SE.

Figure 3. The timing of stimuli presentation for the visual probe attention task used in Experiment 2.

Figure 4. Key findings from Experiment 2: (A) Reaction times from the dotprobe attention task when CSsweet and the visual were co-located (congruent: ) or in opposite locations (incongruent: ). The left hand panel shows trials when CSsweet were paired with CSneutral cues: the right hand panel contrasts CSsweet against average responses for the three control cues. Data are estimated marginal mean reaction times ± SE (msec), n= 79.

B) changes in rated liking for the three cue types (CSsweet, CSneutral and controls): data are mean ± SE VAS ratings, n=80.
<table>
<thead>
<tr>
<th>Goldplate</th>
<th>M-GreenCircle</th>
<th>Black Circle</th>
<th>Boxes</th>
<th>EightBox</th>
</tr>
</thead>
</table>


A) Layout of the snack intake test

B) Overall snack intake
ITI (100-700msec) + Fixation cross (100msec) + Image display (500msec) * Visual probe (max 1250msec)
A) Reaction time (msec)

B) Change in rated liking for cue

Taste associated with cue