# Do low-calorie sweetened beverages help to control food cravings? Two experimental studies.

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## Abstract

Low-calorie sweetened (LCS) beverages may help consumers to satisfy hedonic food cravings without violating dieting goals, however this remains unexplored. The present research investigated the effect of priming hedonic eating motivations on *ad libitum* energy intake in frequent and non-consumers of LCS beverages. It was hypothesised that energy intake would be greater after the hedonic eating prime relative to a control prime in non-consumers, but that frequent LCS beverage consumers would be protected from this effect. In **Study 1** (*N*=120), frequent and non-consumers were exposed to either chocolate or neutral cues (craving vs. control condition) and then completed a beverage-related visual probe task with concurrent eye-tracking. *Ad libitum* energy intake from sweet and savoury snacks and beverages (including LCS) was then assessed. **Study 2** followed a similar protocol, but included only frequent consumers (*N*=172) and manipulated the availability of LCS beverages in the *ad libitum* eating context (available vs. unavailable). Measures of guilt and perceived behavioural control were also included. In **Study 1**, as hypothesised, non-consumers showed greater energy intake in the craving condition relative to the control condition, but frequent consumers had similar energy intake in both conditions. Frequent consumers (but not non-consumers) also demonstrated an attentional bias for LCS beverage stimuli compared to both sugar and water stimuli. In contrast, in **Study 2** frequent consumers showed greater energy intake in the craving condition relative to the control condition; however, overall energy intake was significantly greater when LCS beverages were unavailable compared to when they were available. Ratings of guilt were higher and perceived control was lower in the LCS-unavailable condition relative to the LCS-available condition. **Conclusions**: LCS beverages did not consistently protect consumers from craving-induced increases in energy intake. However, frequent consumers consumed fewer calories overall when LCS beverages were available (relative to unavailable), as well as perceiving more control over their food intake and feeling less guilty.

## Introduction

Low-calorie sweetened (LCS) beverages have emerged as a strategy to reduce total energy intake, providing sweet taste without additional calories and thereby potentially assisting in weight loss (Panahi, et al. 2013; Mattes, Shikany, Kaiser, & Allison, 2011). Despite their popularity, the influence of LCS beverages on energy intake and weight maintenance has been a contentious issue. Some argue that LCS beverages encourage a preference for hedonically pleasing food and increase the risk for weight gain and obesity (Swithers, 2013; Swithers, 2010; Nettleton et al., 2009; Fowler et al., 2008), although this may be a non-causative association. Indeed, a recent systematic review found that consumption of LCS beverages, when used as a substitute for sugar, is associated with *reductions* in energy intake and body weight (Rogers et al., 2016). Given this controversy, understanding the motivations behind consumption of LCS beverages is of importance. However, little is known about the underlying psychological drivers behind frequent consumption of LCS beverages and how these psychological factors impact on eating behaviour.

To address this research gap, Appleton and Conner (2001) previously investigated the characteristics associated with frequent consumption of LCS beverages. They found that frequent consumers of these beverages are typically overweight but also have high dietary restraint and body weight concerns relative to non-consumers of LCS beverages. Restrained eaters are motivated to control their weight by restricting their food intake; however, they are often unsuccessful in these attempts and their eating behaviour is characterised by periods of food restriction and disinhibited eating (Lowe, 2002; Gorman & Allison, 1995). The goal conflict model proposes that dietary restraint is difficult because these individuals are attempting to juggle two conflicting goals; their hedonic goal of enjoyment of eating while also satisfying their long-term goal of weight maintenance (Stroebe, Mensink, Aarts, Schut, & Kruglanski, 2008). This is a challenge for dieters because low-energy, “diet” foods are often less hedonically pleasing than foods with higher calorie contents (Drewnowski, 2003).

Drawing on the above, it is plausible that LCS beverages may benefit some individuals because these products are able to satisfy food cravings and/or hedonic desire for sweetness while also enabling maintenance of dieting goals (thereby realigning previously conflicting goals). However systematic investigation of this has yet to be conducted and the mechanisms for how LCS beverages might influence energy intake are unclear.

One possibility is that LCS beverages may act as a "diet prime", reminding consumers of their dieting motivations and thereby helping to regulate their eating behaviour. While this has not been investigated specifically for LCS beverages, several studies have demonstrated that exposing participants to cues linked with their longstanding diet goals can trigger goal-directed behaviour (Buckland, Finlayson, Edge, & Hetherington, 2014; Buckland, Finlayson, & Hetherington, 2013; Fishbach, Friedman, & Kruglanski, 2003). For example, restrained eaters do not overeat following pre-exposure to palatable food cues when they are reminded of their dieting goal (Papies and Hamstra, 2010; see also Anschutz Van Strien & Engels, 2008, for comparable findings). However, it is important that the primed goal is motivationally relevant to that individual, in that given situation (Custers & Aarts, 2005, Aarts 2007; Fishbach & Trope, 2005; van Koningsbruggen, Stroebe & Aarts, 2011; Papies, Stroebe & Aarts, 2008). Given this link, it is plausible that exposure to LCS beverages may similarly act as a diet prime for frequent consumers of these beverages and thereby enable them to pursue their long-term weight maintenance goals even in situations in which short-term hedonic goals typically prevail. As a result, individuals may feel more in control and less guilty over their eating. Given that negative affect is often associated with increased consumption or emotional eating (Cuijpers, Steunenberg, & Van Straten, 2007; Epel et al., 2001; Greeno and Wing, 1994), determining whether consumption of LCS beverages reduces feelings of guilt and increases perceived behavioural control would also be meaningful.

In line with the goal-conflict model, another possibility is that the presence and availability of LCS beverages acts as a highly salient hedonic cue due to their association with a rewarding experience (i.e. sweet taste). According to incentive-motivational models, repeated exposure to stimuli associated with food reward results in biased attention towards these and any other relevant stimuli (see Field et al., 2016). As a result of this, we would expect frequent consumers of LCS beverages to exhibit a bias in attention towards LCS beverages, and this bias may be further amplified under conditions when hedonic eating motivations are activated. Consistent with this idea, Kemps and Tiggeman (2009) found that participants who were experimentally induced into a temporary state of food craving showed increased attentional bias to chocolate-related pictures, relative to the control condition (see also Smeets, Roefs & Jansen, 2009, and van Dillen & Andrade, 2016, for similar findings). Thus, if LCS beverages are associated with hedonic eating motivations in frequent consumers, we would expect to see an amplified attentional bias towards cues associated with LCS beverage stimuli, particularly when hedonic motivations (i.e. food cravings) are primed.

The overarching aim of the present research was to determine the psychological mechanisms underpinning the effect of LCS beverages on eating behaviour. Specifically, we investigated the effect of priming hedonic eating goals, via a chocolate craving manipulation, on *ad libitum* energy intake in frequent and non-consumers of LCS beverages. It is well-established that food cue exposure and craving increase food intake (Boswell & Kober, 2016), therefore in Study 1, we hypothesised that energy intake would be greater after the craving manipulation relative to the control manipulation in non-consumers. However, we predicted that frequent consumers would be protected from this effect due to the availability of LCS beverages in the *ad libitum* eating context (Hypothesis 1). We also examined attentional bias towards LCS beverage-related stimuli following the craving or control manipulation. We predicted that frequent consumers, but not non-consumers, would show an attentional bias to

LCS beverage stimuli and that this bias would be amplified when frequent consumers were in a state of craving (Hypothesis 2). Study 2 sought to replicate Study 1 while also directly manipulating the availability of LCS beverages and including measures of guilt and perceived behavioural control over eating.

## Study 1 Methods

### Participants

One hundred and twenty university staff and students (Mean age 31.44 ±8.54 years) were recruited to take part in a study investigating the relationship between beverage consumption and behaviour. Prior to attending the laboratory session, participants were identified and classified as frequent and non-consumers of LCS beverages according to a self-reported online Food Frequency Questionnaire (FFQ) assessing consumption of a range of beverages (see Appleton & Conner, 2001). Participants were classified as frequent consumers if they reported consuming >825 ml LCS beverages/day. Non-consumers of LCS beverages were defined by a consumption of 0ml of LCS beverages in addition to >825 ml/d of sugar sweetened beverages (SSB) and/or >825 ml/d of water, to ensure effects of high consumption of beverages were controlled for. In addition to being either frequent or non-consumers of LCS beverages, inclusion criteria required that participants were non-smokers, had no food allergies or intolerances, had never been diagnosed with an eating disorder, and were not on any medication known to affect appetite. Finally, due to the eye-tracking technique used, glasses wearers were unable to take part. All participants completed an online screening questionnaire prior to testing to ensure that they meet all inclusion criteria.

On the basis of their responses to the screening questionnaire, frequent ($N$=60) and non-consumers ($N$=60) of LCS beverages were randomly allocated to either the craving or control condition, in a 2 x 2 between-subjects design. Ethical approval was granted by the University Research Ethics Committee and all participants gave written informed consent before participation.

## Measures and procedures

***Craving condition: exposure***

The craving manipulation was adapted from Kemps and Tiggemann (2009). Participants were requested to pick their favourite chocolate bar from a selection of eight brands of "fun-size" wrapped chocolate bar. They were instructed to unwrap and intensively smell and touch their chosen chocolate bar without tasting it for 2 minutes, to attempt to invoke the sensation of craving. Participants were instructed to write down the name of the chocolate bar and indicate how much they liked it on a 100-mm visual analogue scale (VAS) ranging from "not at all" to "very much". They were then asked to indicate their craving for chocolate at that very moment using a VAS. Participants completed the craving exposure on two occasions, first for two minutes before the Visual Probe Task (VPT) and for a second time (craving booster) for 1 minute, halfway through the VPT (please see below section for detailed description of the VPT).

***Non-craving condition: control***

Participants assigned to the 'control condition' completed a similar protocol to the craving exposure, to ensure that all participants took part in comparable activities. However, instead of being exposed to chocolate, participants were given a basket of eight different coloured wooden blocks, resembling the shape and size of the chocolate bars. The remaining instructions were the same as the craving manipulation; selecting their preferred block, sensualising the block and completing VAS scales for craving chocolate and how much they liked their chosen colour.

***Ad libitum snack intake***

Participants were provided with a variety of snack foods, presented in bowls and invited to eat *ad libitum* for 15 minutes. The food items consisted of the following items: a 150g bowl of Tesco mini flapjacks (Per 100g: 458 Kcals, 21.9g fat), a 115g bowl of Tesco mini brownies (Per 100g: 394 kcals, 15g fat), 44g bowl of two packets of salt and vinegar Snack-a-Jacks (Per bag: 89 kcals, 1.6g fat), 1 x cheese and onion sandwich (Tesco Cheese and Onion, Per pack:

505kcals, 28.4g fat), 2 x Tesco cheese and onion rolls (Per 60g roll: 176 kcals, 9.6g fat), 115g of Tesco millionaire bites (Per 100g: 500 kcals, 28.0g fat). Participants were also offered a 1-litre bottle of sugar sweetened beverage (SSB), of either Coke (Per 100ml: 42kcal, 0g fat) or Sprite (Per 100ml: 14.0g kcal, 0.0g fat), a 1-litre bottle of LCS beverage of either Diet Coke (Per 100ml: 1.6kcal, 0.0g fat) or Sprite Zero (Per 100ml: 0.1kcal, 0.0g fat) and 1-litre bottle of still water (0.0kcal, 0.0g fat). The beverages given were previously decided on based on each participant's screening questionnaire in which they indicated their preferred beverage. In total, the buffet lunch consisted of 3177.35 calories and 143.5g fat. Plates, bowls and beverages were covertly weighed before and after consumption to determine food intake.

***Attentional bias; visual probe task (VPT)***

All stimuli were presented using Inquisit version 3 (Millisecond software, 2012). The VPT tasks used images of three different beverage types - LCS, SSB and water - and depicted a range of beverage-related scenes and bottle varieties (e.g., 1 litre bottle of diet coke, a can of coke being poured into a glass). These three beverage types were used to generate three categories of image pairs: (1) LCS beverages vs. water images, (2) LCS beverages vs. SSB images, and (3) Water vs. SSB images. Within each image pair category, there were eight image pairs, which each appeared eight times. The task thus consisted of 192 trials (in line with Christiansen, Mansfield, Duckworth, Field and Jones, 2015). Images were 125mm high x 125 mm wide. Within each pair, images consisted only of the beverages and they were matched as closely as possible for colour, complexity, brightness, shape, and size. Prior to attending the laboratory, frequent consumers indicated their preferred LCS beverage and similarly, non-consumers indicated their preferred SSB. Participants viewed their chosen beverage during the task (i.e., if participants opted for Sprite Zero, the LCS beverage images viewed in the task were all Sprite Zero). Using personalised stimuli has been shown to significantly improve the internal reliability of the VPT (i.e. Christiansen, et al., 2015). We decided to include both SSB and water as controls to determine if frequent consumers of LCS beverages were distracted more by LCS beverage stimuli even when sugar beverages were also present. Eight additional images pairs depicting stationery items and household items were used for the practice trials. The order of trials was randomised for each participant.

Each trial began with a white fixation cross presented in the centre of the screen for 500ms. This was followed by a pair of images presented for 2000ms, one picture on the left of the screen and the other on the right, 60 mm apart. Immediately after this, one of the images was replaced by a probe (a white arrow on a black background, pointing up or down). Participants were instructed to respond as quickly as possible to the orientation of the probe by pressing the corresponding key, to indicate the location of the probe. The inter-trial interval was 500ms. Participants first completed 8 practice trials in which neutral image pairs (stationery and household images) were presented. The task lasted approximately 25 minutes. The complete task was divided into two blocks of 96 critical trials each, with a break in the middle to maintain craving (i.e., craving booster). Reaction time to probes was measured on each trial (see supplementary material).

***Eye-movement measurements***

Eye-movements were recorded during the VPT using an Eye-Trac D6 desktop mounted camera (Applied Science Laboratories, Bedford, MA).

***Additional measures and trait eating questionnaires***

*Attitudes and beliefs towards LCS beverages:* Attitudes towards LCS beverages were assessed using a novel questionnaire previously developed by our research group, containing two subscales: appetite and weight management (7 items) and palatability and enjoyment of LCS beverages (7 items). Participants indicated the extent to which they agreed with each statement (e.g. “I believe LCS beverages help me to manage my cravings for sweet foods”) on a 7-point Likert scale which ranged from “Strongly disagree to “Strongly agree”. Subscale scores were determined by the mean score of the relevant items. Both scales had high internal reliability: appetite and weight management ($\alpha$=.96), and palatability and enjoyment ($\alpha$=.95)’.

In addition, The Dutch Eating Behaviour Questionnaire (DEBQ, van Strein et al., 1986), The Attitudes to Chocolate Questionnaire (ACQ, Benton, Greenfield & Morgan, 1998) and Three Factor Eating Questionnaire (TFEQ, Stunkard & Messick, 1985) were used to provide descriptive information about the sample (see supplementary material for a full description of these measures).

***Appetite ratings***

Levels of craving for chocolate, hunger, fullness, and thirst were assessed using 100mm-VAS. Each scale was anchored by 'Not at all' on the left and 'Extremely' on the right. Appetite VAS measures have been shown to have good validity and reliability (Blundell et al., 2010).

***Procedure***

Testing took place in the Department of Psychological Sciences on the University of Liverpool campus. Each participant attended one 60-min session. All sessions were conducted between 12pm and 6pm. Upon arrival, participants provided written informed consent and confirmed that they had not eaten for at least 3 hours prior to the study. Additionally, frequent consumers were asked to refrain from consuming any LCS beverages 24 hours in advance. Upon arrival, participants indicated their current appetite ratings (of hunger, fullness, thirst and craving for chocolate) using VAS (Time 1). Following this, participants completed the respective craving or control conditions for 2 minutes. A second measure of appetite was taken (T2). Participants then performed the VPT and concurrent eye-tracking task. There was an interval in the middle of the task and participants were once again subjected to the craving or control exposure for 1 minute (i.e. craving booster) to ensure that participants assigned to the craving condition maintained their increased levels of craving. They were asked to smell and touch the chocolate (or wooden block) for 1 minute in the middle of the task and indicate the level of craving on a VAS. Subsequent appetite ratings were also assessed (T3). Participants then completed the second half of the VPT and eye-tracking task. Following this, participants completed appetite ratings again (T4). Subsequently, participants were given a selection of sweet and savoury foods and beverages which they could consume *ad libitum* for 15 minutes. As part of the cover story participants were given the selection of foods under the pretence that, because they were asked to refrain from consuming food for 3 hours, we offered everyone some food before they could leave. Participants were invited to consume as much or as little as they wanted. Food and beverage intake were measured by covertly weighing the bowls and drinks before and after consumption. Following this, participants' ratings of appetite were measured again (T5). Participants then filled in the DEBQ, TFEQ, Attitudes and beliefs towards LCS beverages questionnaire and the ACQ and measures of height and weight were taken to calculate Body Mass Index (BMI). To ensure the absence of demand characteristics, participants were asked to indicate what they thought the aims of the study were. Finally, participants were debriefed and thanked for their time.

## Data analysis

### *Energy intake*

The amount (in g) of food consumed was converted into calories. A 2(condition; craving, control) x 2(consumer group; freq. non-consumers) ANOVA on energy intake was conducted (Hypothesis 1), with condition and consumer group as the between-subjects factors and *ad libitum* energy intake as the dependent variable. We also conducted exploratory analyses to examine the effects of condition and consumer group on intake of specific food-types (i.e. sweet foods, savoury foods, beverages).

### *Attentional bias scores*

Eye-movement data: For eye-movement data, gaze dwell time was measured. Gaze dwell time was determined as the total amount of time in milliseconds that participants spent fixating on each image over the 2000ms of each trial. In accordance with previous research (i.e. Christiansen et al., 2015), fixations were defined as a stable eye-movement within one degree of visual angle for 100ms or longer. Attentional bias scores for LCS beverages relative to water were determined by subtracting mean gaze dwell time on water images from mean gaze dwell time on LCS beverage images. Similarly, the attentional bias score for LCS beverages relative to SSB was determined by subtracting the mean gaze dwell time on SSB images from mean gaze dwell time on LCS beverage images. A positive score indicated an increased attention towards LCS beverages, while a negative score indicated an attentional bias towards the control (i.e. water or sugar beverages) images.

The following analyses were conducted to test Hypothesis 2:

Gaze dwell times bias: A 2 (condition; craving vs control) x 2 (consumer group; freq. vs. non-consumers) ANOVA was conducted with condition and consumer group as between-subjects factors and gaze dwell time bias for LCS beverages relative to water as the dependent variable. The analysis was then repeated with gaze dwell time bias for LCS beverages relative to SSB as the dependent variable. Analyses conducted on the reaction time data for the VPT task are available in the supplementary material.

## Study 1 Results

### Participant characteristics

Due to technical problems with the eye-tracker, data from 5 participants were lost. Four participants had excessive missing data from the VPT (>25% reaction times missing) and were also excluded; the remainder had <5% of data missing. Nine additional participants were therefore recruited to replace the lost data. Participant characteristics of the final sample are provided in Table 1. Independent samples t-tests confirmed that frequent consumers had significantly higher BMI, restraint, disinhibition and trait guilt associated with chocolate consumption relative to non-consumers. Additionally, frequent consumers had significantly higher beliefs that LCS beverages were palatable and effective in controlling appetite and weight relative to non-consumers. There were no significant differences between consumer groups on remaining characteristics, (*ps*>. 226). A chi-squared test showed that there was no significant differences in the number of males and females between consumer groups, $\chi^2(2)$

=.051, *p*=.822. Importantly, independent t-tests confirmed that participants did not differ between the craving and control conditions with regard to any of these characteristics (*ps*>.131).

**Table 1.** *Descriptive statistics stratified by consumer group. Values are means with standard deviations in parentheses*

| **Characteristics** | **Frequent consumers of LCS beverages (n=60)** | **Non-consumers of LCS beverages (n=60)** |
|---|---|---|
| Age (y) | 30.45 (9.17) | 32.43(7.81) |
| BMI ($kg/m^2$) | 26.29(4.26) | 22.80(3.48)* |
| TFEQ | | |
| Disinhibition | 8.35(2.62) | 6.33(2.77)* |
| DEBQ | | |
| Restraint | 3.24(1.07) | 2.63(1.10)** |
| Emotional | 2.96(.90) | 3.01(.89) |
| External | 3.25(.47) | 3.30(.53) |
| Attitudes & Beliefs | | |
| Appetite & Weight management | 5.61(6.07) | 2.58(1.16)* |
| Palatability & Enjoyment | 5.10(1.25) | 3.31(1.43)* |
| ACQ | | |
| Trait Functional | 34.66(14.60) | 35.53(15.50) |
| Trait Guilt | 44.56(16.66) | 31.91(19.04)* |
| Trait Craving | 51.62(18.27) | 47.07(22.46) |

**TFEQ= Three Factor Eating Behaviour. DEBQ= Dutch Eating Behaviour Questionnaire. ACQ= Attitudes to Chocolate Questionnaire. *$p$<.001, **$p$<.05** frequent consumers vs. non-consumers.

Analysis of the craving ratings indicated that the craving manipulation was effective in inducing craving in participants in the craving condition relative to the control condition. Full results for ratings of craving for chocolate, hunger, fullness and thirst are available in the supplementary material.

## Energy intake

There was a significant condition x consumer-group interaction on energy intake, $F(1,116)=5.30$, $p=.023$, $\eta_p^2=.04$ (Fig. 1). Planned comparisons showed that, consistent with our first hypothesis, frequent consumers consumed similar amounts in both the craving and control conditions $t(58)=1.11$, $p=.270$, $d=.29$ whereas non-consumers consumed significantly more in the craving (M=562.19 kcal; ±405.33), relative to the control (M=374.74 kcal; ±255.70) condition, $t(48.93)= -2.14$, $p=.037$, $d=.55$. There were no main effects of consumer group, $F(1,116)=0.60$, p=.441, $\eta p^2=.01$, or condition $F(1,116)=0.53$, $p=.467$, $\eta_p^2=.01$.

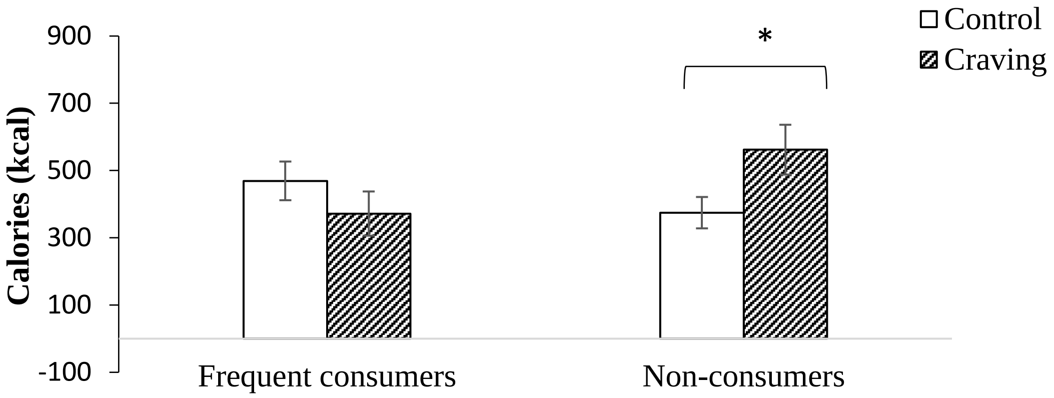


**Fig. 1** Mean energy intake following craving and control conditions in frequent and non-consumers (*$p=.037$). Error bars represent standard error of the mean

Correlational analyses revealed that there was a significant positive association between craving and energy intake in non-consumers ($r= .402$, $p<.001$) but not in frequent consumers, ($r=.005$, $p=.968$).

***Exploratory analyses on energy intake***

To further explore the interaction between condition and consumer group on energy intake, a mixed 3-way ANOVA was conducted, with condition (craving vs control) and consumer group (freq. vs non-consumer) as the between-subjects variables and food type (sweet, savoury and beverages) as the within-subjects variable and intake reported in kcal as the dependent variable. There was no interaction between condition x consumer group x food type, $F(1.74, 202.06)=1.58$, $p=.211$, $\eta_p^2=.01$. This indicates that the interactive effect of condition and consumer group on total energy intake, was not driven solely by calories from sweet, or savoury foods, or beverages.

To further explore potential differences in the volumes of beverages consumed, we conducted a mixed-ANOVA, with condition and consumer group as between-subjects variables, beverage type (LCS beverage, SSB, water) as the within-subjects variable, and intake reported in ml as the dependent variable. There were main effects of beverage type, $F(1.6, 190.16)=34.20$, $p<.001$, $\eta_p^2=.23$ and consumer group, $F(1,116)=13.41$, $p<.001$, $\eta_p^2=.10$. There was also an interaction between consumer group x beverage type, $F(1.6, 190.16)=160.21$, $p<.001$, $\eta_p^2=.58$. Post-hoc t-tests revealed that frequent consumers drank significantly more LCS beverages ($p<.001$; M=364.58ml; ±142.50) relative to non-consumers (M=0.00ml ±0.00). Contrastingly, non-consumers drank significantly more SSB ($p<.001$; M= 99.43 ml ±145.38), and water ($p<.001$; M=185.29.ml; ±176.74) relative to frequent consumers (M=0.00ml; ±0.00, and M=19.57ml; ±67.28, respectively). Furthermore, frequent consumers drank significantly more overall (M=384.15ml; ±160.17) relative to non-consumers (M=284.72ml; ±138.69), $t(118)=3.64$, $p<.001$, $d=.66$. There were no interactions between condition and beverage type, or between condition, consumer group and beverage type ($ps>.146$). This indicates that the amount of the different beverages consumed in the two consumer groups was not influenced by whether participants were in the craving or control condition.

## Attentional bias

Gaze dwell time bias: Results showed a main effect of consumer group on dwell time bias for LCS beverage-related images relative to water images, $F(1,116)=8.10$, $p=.005$, $\eta_p^2=.07$, such that frequent consumers exhibited an increased attentional bias compared to non-consumers (Fig. 2, panel A). There was no main effect of condition, $F(1,116)=0.68$, $p=.410$, $\eta_p^2<.01$ and contrary to Hypothesis 2, no condition x consumer group interaction on gaze dwell bias for LCS beverage-related images relative to water images, $F(1,116)=2.89$, $p=.592$, $\eta_p^2<.01$.

The same pattern of results was found when dwell time bias for LCS beverages images relative to SSB-related images was the dependent variable (Fig. 2, panel B). There was a main effect of consumer group, $F(1,116)=11.63$, $p<.001$, $\eta_p^2=.09$ such that frequent consumers exhibited a greater attentional bias than non-consumers. There was no main effect of condition, $F(1,116)=.01$, $p=.904$, $\eta p^2<.01$, and no interaction between condition and consumer-group, $F(1,116)=.18$, $p=.677$, $\eta p^2<.01$.

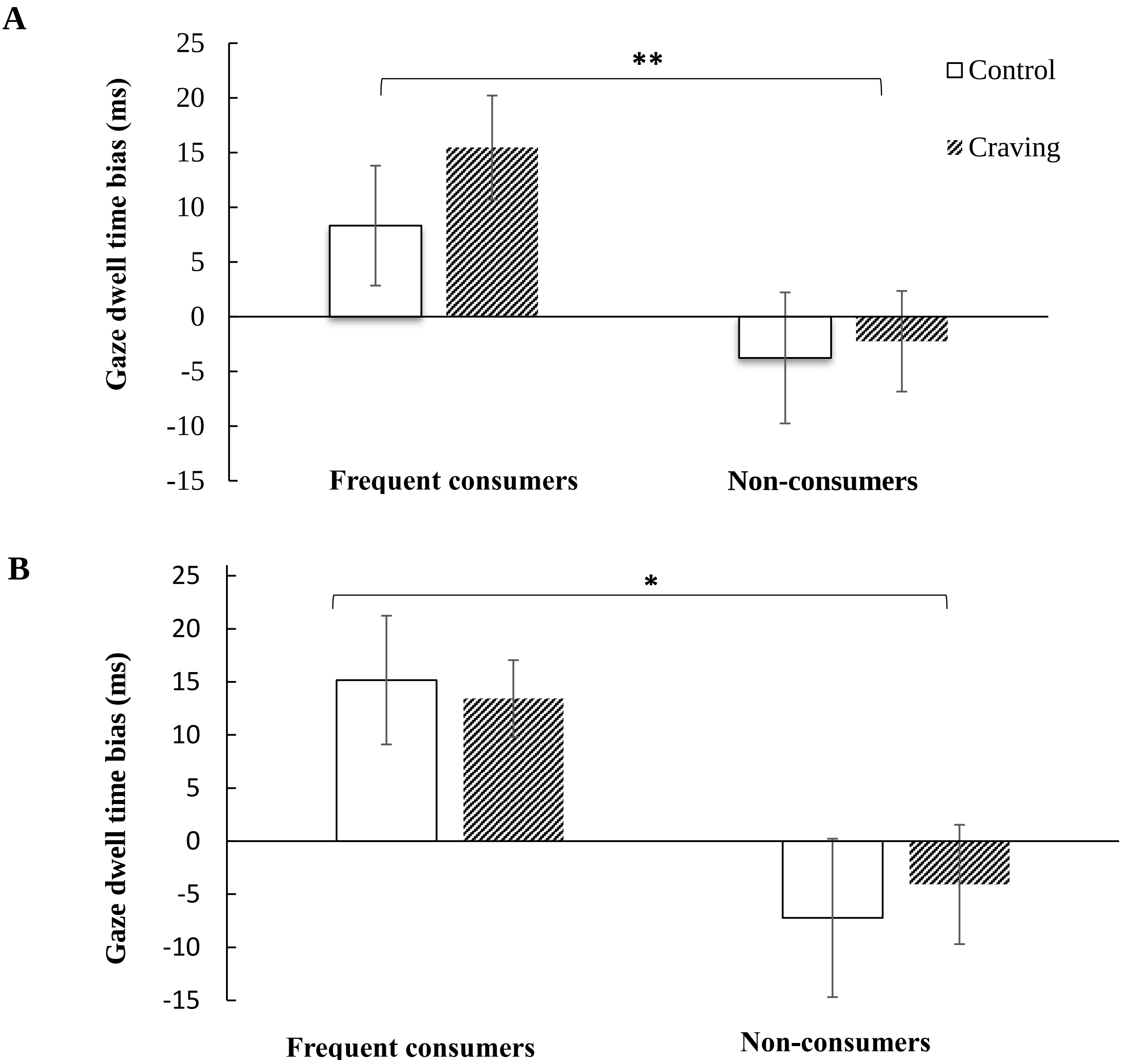


**Fig.2** Mean gaze dwell bias (in milliseconds with standard error bars) for LCS beverages relative to Water (Panel A), Mean gaze dwell bias for LCS beverages relative SSB (Panel B). *$p<.001$ $p$** $<.05$. A positive score indicates an increased attentional bias for LCS beverages, relative to water or SSB.

## Interim Discussion

Study 1 found that frequent consumers of LCS beverages did not show greater energy intake following the craving exposure relative to the control exposure, despite reporting significant increases in chocolate craving (indicating activation of hedonic eating motivations). It is well-established that cue-induced craving is associated with subsequent increased eating (Belfort-DeAguiar & Seo, 2018; Boswell and Kober, 2016), and therefore it is meaningful that frequent consumers of LCS beverages did not exhibit this behavioural response in our study. Contrastingly, non-consumers consumed more calories in the craving condition relative to the control condition. Moreover, they showed a significant positive association between craving and energy intake while there was no evidence for this link in frequent consumers.

There were some notable differences between frequent and non-consumers; frequent consumers had significantly higher BMI, dietary restraint, body weight concerns and disinhibition relative to non-consumers. Given the strong relationship between disinhibited eating behaviours and exposure to palatable foods (Bryant, King & Blundell, 2007; Bellisle et al., 2004), we might expect that frequent consumers would be *more* susceptible to hedonic eating cues following the craving manipulation, However, this was not the case possibly because frequent consumers were able to satisfy their hedonic eating goal by consuming LCS beverages, whilst also pursuing their more long-term goal of weight management. However, against this idea, there was no effect of being in the craving-condition on LCS beverage intake in frequent consumers (i.e., we might expect them to consume *more* LCS beverages in the craving condition, relative to the control condition, if these beverages were being used to satisfy food cravings, but this was not the case).

A further novel finding was that frequent consumers showed an attentional bias towards images of LCS beverages, whereas non-consumers showed no evidence of this bias. Overall, these results suggest that frequent consumers are drawn towards LCS beverages over other beverages including SSB. In light of the recent controversy surrounding LCS beverages and whether they encourage a preference for sweet foods and beverages in the diet (Casperson, Johnson & Roemmich, 2017; Sylvetsky & Dietz, 2014; Swithers & Davidson, 2008), our findings suggest that this attentional bias is specific to LCS beverages, rather than reflecting a more general bias towards sweet-tasting products.

In Study 2, we aimed to replicate the effect of the craving manipulation on energy intake in frequent consumers. We also aimed to determine whether this effect was due to LCS beverages being available for consumption (and thereby satisfying hedonic eating motives). In order to do this, we manipulated the availability of LCS beverages (available vs. unavailable) in the *ad libitum* eating context. We predicted that in the LCS unavailable condition, participants would show greater energy intake when in a state of craving relative to the non-craving control condition (i.e., mirroring the result found in non-consumers in Study 1). However, in the LCS available condition, we predicted that there would be no difference in food consumption between the craving and non-craving control condition (Hypothesis 1). We also explored the impact of LCS beverages on eating-related guilt, enjoyment of the meal, and perceived behavioural control. We predicted that, in the LCS unavailable condition, participants would report higher guilt, lower meal enjoyment and lower perceived control in the craving condition relative to the control condition. However, in the LCS available condition, we predicted there would be no difference between the craving and control conditions (Hypothesis 2).

## Study 2 Method

### Participants

Participants (N=172) were frequent consumers of LCS beverages, as determined using the Appleton and Conner (2001) FFQ which was completed during an online pre-study screening questionnaire. In a 2 x 2 between-subjects design, participants were randomly allocated either to the craving or control condition, and the LCS available or LCS unavailable condition, generating four independent groups. We powered the study (80% power) using GPOWER 3.1 to detect a medium-large effect size ($f$=.35, on the basis of Study 1) at an alpha level of *p*=.05 and recruited the required sample (*N*=172) to detect a significant interaction between LCS availability and craving exposure in relation to food intake.

## Measures and procedure

The overall method was the same as in Study 1, with the following changes.

1. As we were specifically interested in the effect of craving exposure and LCS availability on food intake in frequent consumers, we only recruited frequent consumers.
2. To investigate the effect of LCS availability on food intake in response to the craving manipulation (vs. control), LCS beverage availability was experimentally manipulated. During the *ad libitum* buffet, LCS beverages were either available with the snack food (available condition) or they were unavailable (non-available condition). Participants were offered one type of SSB (their preferred choice from Coke, Pepsi and Seven-up) and water in the unavailable condition, while the LCS-available condition they had all three beverage types available (SSB, water and LCS beverages).
3. We did not have a specific hypothesis regarding attentional bias, however in order to maintain consistency between the two studies, participants completed the same VPT with images of LCS, SSB and water beverages. The eye-tracking element was removed for ease of completion and only responses based on reaction times were collected. Results are provided in the supplementary material.
4. Ratings of food-related self-control and guilt were obtained after the *ad libitum* buffet. Perceived control over food intake was measured by answering the following questions: "How much control did you feel you had over how much food you ate?", and "How in control did you feel about the food choices you made?" using a 100mm

VAS. Rating across the two scales had relatively high internal consistency (α = 0.75), and thus scores were averaged to form one composite variable.

5. Eating-related guilt concerns were assessed by asking “do you feel guilty with the amount of food you have consumed?” and “Do you feel guilty with the types of food you have consumed?”. Responses were indicated using 100mm VAS scale, ranging from “not guilty” to “extremely guilty”. Ratings for guilt were combined into a composite variable, due to their high internal consistency (α =0.83). All of these additional measures were presented, and responses recorded, on a laptop computer using Inquisit 3.0. (Millisecond Software, 2012).
6. Finally, after the *ad-libitum* food intake, ratings for meal enjoyment were obtained. Participants were asked to indicate how enjoyable they found the food. Responses were provided on a 100mm VAS scale, ranging from “not enjoyable at all” to “extremely enjoyable”.

The experiment took approximately 60 minutes to complete.

### Data analysis

Four separate 2(condition; craving vs control) x 2 (group; LCS available vs. LCS unavailable) ANOVAs were conducted, on the following dependent variables: energy intake (Hypothesis 1), guilt, perceived behavioural control, and meal enjoyment (Hypothesis 2), with condition and group as between-subjects variables. We also conducted exploratory analyses to examine the effects of group (i.e. LCS available vs LCS unavailable) on intake of specific food-types (i.e. sweet foods, savoury foods, beverages).

## Study 2 Results

### Participant characteristics

One-way ANOVAs revealed no differences between the experimental conditions with regard to age, BMI, restraint, emotional and external eating traits, indicating that all groups were evenly matched (*ps*>.105). Participant characteristics are provided in Table 2. A chisquare analysis confirmed that there was no difference in the number of males and females between conditions, $\chi^2$ (3)=3.81, $p$=.283.

**Table 2.** *Descriptive statistics for LCS beverage (available vs. unavailable) and craving (vs. control) groups. Values are means with standard deviations in parentheses*

| **Characteristic** | **Craving LCS available** | **Control LCS available** | **Craving LCS unavailable** | **Control LCS unavailable** |
|---|---|---|---|---|
| N | 43 | 43 | 43 | 43 |
| Age (y) | 29.05 (12.94) | 27.00(9.48) | 26.86(11.95) | 28.16(12.66) |
| BMI (kg/m2) | 26.94(4.67) | 25.90(4.19) | 27.36(3.97) | 27.54(3.71) |
| DEBQ | | | | |
| Restraint | 3.25(.78) | 3.15(.87) | 3.16(.84) | 3.25(.75) |
| Emotional | 2.91(.91) | 2.79(.84) | 3.05(.81) | 2.75(.76) |
| External | 2.92(.85) | 2.93(.73) | 2.86(.91) | 2.83(.75) |

Craving ratings indicated that the craving manipulation was effective in inducing craving in participants in the craving condition relative to the control condition (see supplementary material for results for appetite ratings of craving, hunger, fullness and thirst).

## Energy intake

Inconsistent with Hypothesis 1, there was no significant interaction between condition and group on energy intake, $F(1,168)=0.59$, $p=.808$, $\eta p^2 <.01$. There was a main effect of condition, $F(1,168)= 6.64$, $p=.011$, $n_p^2= .04$ (see Fig. 3); participants consumed significantly more overall in the craving condition relative to the non-craving control condition. There was also a main effect of group, $F(1,168) =5.87$, $p=.016$, $n_p^2 =.03$; participants consumed more calories overall when LCS beverage were unavailable (M=647.85 kcal ±332.19) relative to when they were available (M=516.80 kcal ±385.20).

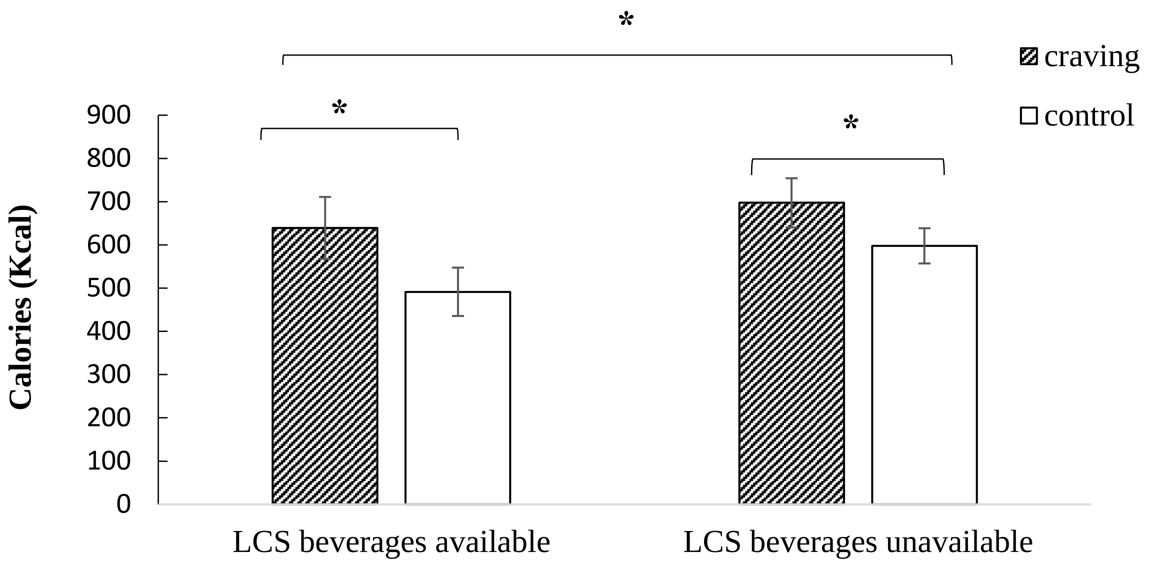


**Fig**. **3** Mean energy intake in the craving and control conditions and in the LCS available and unavailable groups. *p** <.05. Error bars represent standard error of the mean.

Correlational analyses revealed that there was no positive association between craving and energy intake in the LCS available group ($r$= .134, $p$=.219) or the LCS unavailable group ($r$= -.011, $p$=.923).

***Exploratory analysis on energy intake***

To further explore the significant main effect of group (i.e. LCS available vs LCS unavailable) on energy intake, we conducted a mixed ANOVA with group (LCS available vs LCS unavailable) as the between-subjects variable and food type (sweet, savoury and beverages) as the within-subjects variable, and intake reported in kcal as the dependent variable (see also Table S1 for a breakdown of means for each food type in the different groups). There was no group x food type interaction, $F(1.72, 292.11) =.73$, $p$=.485 $\eta_p^2<.01$. This indicates that the main effect of group on total energy intake was not driven solely by calories from sweet, or savoury foods, or beverages.

To further explore potential differences in the volumes of beverages consumed, we conducted a mixed-ANOVA, with condition (craving vs control) and group (LCS available vs LCS unavailable) as between-subjects variables and beverage type (SSB, water) as the within-subjects variable, and intake reported in ml as the dependent variable (it was not possible to include LCS beverages in this analysis due to them only being present in the available condition). There were main effects of beverage type, $F(1,167)=87.03$, $p<.001$, $\eta_p^2=.34$ and group, $F(1,167)=211.13$, $p<.001$, $\eta_p^2=.56$, and an interaction between group and beverage type, $F(1,167)=36.14$, $p<.001$, $\eta_p^2=.18$ Post-hoc t-tests revealed that participants drank SSB beverages (M=41.29ml; ±83.42) when LCS beverages were unavailable, but they did not consume any SSB (M=0.00ml ±0.00) in the available condition, $t(85)= -4.59$, $p<.001$. Furthermore, participants drank significantly more water (M=187.94ml; ±117.87) when LCS beverages were unavailable relative to the LCS available group, (M=31.71ml; ±57.74) $t(123.57)=-11.04$, $p<.001$. There was no main effect of condition or condition x group interaction (both *ps*>.230).

There was also an interaction between condition x group x beverage type, $F(1,167)=6.20$, $p=.014$, $\eta_p^2=.04$. To understand this further, separate 2(condition; craving vs control) x 2 (group; LCs available vs. LCS unavailable) ANOVAs were conducted, on the following dependent variables: SSB (ml) and water (ml) intake. Condition x group interaction for SSB intake was non-significant ($p=.081$), however there was a significant interaction between condition x group for water consumption $F(1,168)=5.22$, $p=.024$, $\eta_p^2=.03$. Post-hoc t-tests revealed that participants consumed more water in the craving condition relative to the control condition when LCS beverages were available, however this effect was only marginally significant, $t(75.59)=1.89$, $p=.063$. In the LCS unavailable group, there was no difference in water consumption between the craving and control condition, $t(84)=-1.62$, $p=.109$.

## Perceived behavioural control

Inconsistent with our second hypothesis, there was no interaction between condition and group on perceived control over food consumed, and there was also no significant main effect of condition (both *ps*>.290). However, there was a main effect of group, $F(1,168)=15.36$, $p<.001$, $\eta_p^2 =.08$; perceived behavioural control was significantly lower in the unavailable condition relative to the available condition (Fig. 4).

### Guilt over food intake

Similar to behavioural control, and against our second hypothesis, there was no condition x group interaction on guilt over food consumed, ($p$=.332). There was a main effect of group, $F(1,168)=9.97$, $p$=.002, $\eta_p^2$ =.06; guilt ratings were significantly higher in the unavailable condition relation to the available condition. There was also a main effect of condition $F(1,168)=5.31$, $p$=.022, $\eta_p^2$ =.03; guilt ratings were significantly higher in the craving condition compared to the control condition.

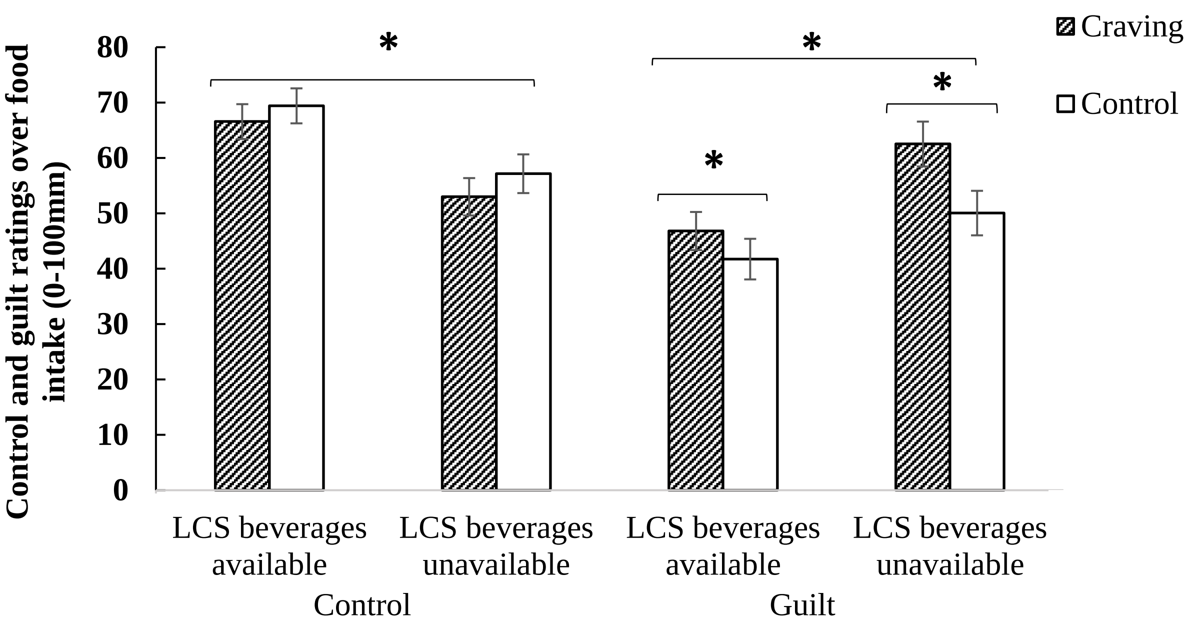


**Fig. 4** Mean perceived control and guilt over food intake ratings following *ad libitum* food intake in the available and unavailable conditions, * $p$<.05. Error bars represent standard error of the mean.

### Meal enjoyment

There was no condition x group interaction or main effect of condition (both *ps*>.445). There was a main effect of group, $F(1,168)=5.57$, $p$=.019, $\eta p^2$=.03, participants reported lower meal enjoyment in the unavailable condition (M=64.44 ±22.94) relative to the available condition (M=71.94 ±18.30).

## General Discussion

The present studies examined the impact of priming hedonic eating goals on energy intake in frequent and non-consumers of LCS beverages. Study 1 aimed to determine whether frequent consumers would be protected from craving-induced increases in energy intake, whereas non-consumers were predicted to show greater energy intake in the craving condition relative to control condition. Results supported this prediction. A potential explanation is that, because LCS beverages were available for consumption in the *ad libitum* eating context, they may have satisfied the frequent consumers' craving for chocolate (however, there was no corresponding increase in LCS beverage intake in the craving condition, relative to the control condition, in frequent consumers). LCS beverages contain almost zero calories which would mean that participants could maintain their dieting goals and the presence of LCS beverages in the eating context may have further served as an additional diet prime. This is consistent with Papies and Hamstra's (2010) and Anschutz et al.'s (2008) work, illustrating that the subtle activation of a diet goal can motivate individuals to pursue it, even when surrounding by hedonic food cues. That non-consumers ate more following the craving exposure relative to the control exposure is not surprising given the substantial evidence indicating that exposure to palatable food cues increases food consumption (Boswell & Kober, 2016; van den Akker, Jansen,Frentz, & Havermans, 2013; Coelho, Polivy Herman & Pliner, 2009; Jansen et al., 2008). Study 1 thus supports the idea that LCS beverages may benefit some individuals, perhaps by subtly reminding them of their weight maintenance goals whilst helping to satisfy their desire for sweetness.

In Study 2, we directly manipulated the availability of LCS beverages in the context of the craving (relative to control) manipulation; however, we failed to replicate the protective effect of LCS beverages on craving-induced energy intake in frequent consumers. Participants ate more in the craving condition relative to control condition regardless of whether LCS beverages were available or unavailable indicating that the presence and consumption of LCS beverages was not sufficient to satisfy hedonic eating motivations. On this basis, it is not possible to conclude that LCS beverages reliably protect individuals from craving-induced increases in food consumption. The reason for the conflicting findings in the two studies is not clear. It is possible that there were differences between the samples of frequent consumers in Studies 1 and 2; however, inspection of the data indicates that these participant groups were similar on variables such as age, BMI, and eating behaviour traits. It is possible that the result in Study 1 is spurious, and further studies are needed in different populations to determine the reproducibility of this finding.

However, in Study 2 we did find that overall food intake was significantly higher when LCS beverages were unavailable relative to when they were available. Participants in the unavailable condition also reported lower perceived behavioural control (i.e., self-efficacy), lower meal enjoyment and higher eating-related guilt relative to the condition when LCS beverages were available. This indicates that when frequent consumers are able to consume these beverages, they feel more in control over their food intake and less guilty. This is important because previous research indicates that when unhealthy food items become associated with negative emotions such as guilt, this can lead to feelings of helplessness and lack of control over eating (Rozin, Bauer, & Catanese, 2003; Tangney et al., 2007 Kuijer & Boyce, 2014; Kuijer, Boyce, & Marshall, 2015). Food-related guilt may, in turn, lead to unhealthier food choices, impulsive eating and long-term weight gain (e.g., Macht, 2008; de Witt Huberts, Evers & de Ridder, 2013). Furthermore, literature has shown that an increase in guilt is likely to be accompanied by a decline in pleasure derived from eating (Lindeman & Stark, 2000; Macht & Dettmer, 2006; Macht et al., 2003), which is consistent with our findings (i.e., higher guilt and lower meal enjoyment in the LCS-unavailable condition relative to the available condition).

An interesting finding was that participants had lower meal enjoyment in the LCS unavailable condition, relative to the available condition, despite consuming more food. This suggests that when frequent consumers do not have access to LCS beverages, they may feel their desire for sweetness is less satisfied and may subsequently consume more hedonically pleasing food as a way to satisfy this. Given the growing interest surrounding LCS beverages, our findings suggest that frequent consumers are perhaps more vulnerable to temptation and over-consumption when LCS beverages are unavailable. Therefore, LCS could play a role a meaningful role in reducing energy intake.

To our knowledge, Study 1 is the is the first to show that frequent LCS beverage consumers have an attentional bias towards LCS beverage-related cues relative to both sugar and water beverage cues as measured by eye-tracking, whereas no such bias was seen in the non-consumers. This finding supports previous research, suggesting that individuals selectively attend to environmental stimuli that are congruent with self-relevant concerns (Field et al., 2016; Kemps & Tiggemann, 2009). It also suggests that frequent consumers view LCS beverages as hedonically-desirable and that cues associated with LCS beverages are motivationally relevant to these individuals. The specific bias towards LCS beverages, rather than a bias towards other sweet beverages, is an important finding and suggests that frequent consumers' attentional bias is specific to LCS beverages rather than reflecting a general preference for sweet products. This lends support to initial evidence that exposure to sweet taste does not increase a subsequent preference for sweet products (Appleton et al., 2018).

In Study 1, we also predicted that attentional bias to LCS beverages would be amplified in the craving condition (i.e. when hedonic eating motivations were activated) relative to the control condition, consistent with Kemps and Tiggeman (2009). However, this was not supported. This lack of effect of craving exposure on attentional bias in the frequent consumers could be because these individuals are naturally drawn towards LCS-beverage stimuli which could create a ceiling effect. Notably, we used personalised stimuli so that the attentional bias towards each consumer's favourite LCS beverages was assessed. This is consistent with work by Christiansen et al., (2015) on the use of personalised stimuli to improve the internal reliability of attentional bias.

The present studies have several strengths and limitations. Notable strengths include the use of personalised LCS beverage-stimuli such that the task was tailored to the preferred LCS beverage of that individual. The research also employed direct measurement of food intake in a controlled laboratory setting. In Study 1, frequent consumers differed from non-consumers on BMI, disinhibition, restraint, and trait guilt, and in future research it would be advisable to include a control group of non-LCS beverage consumers who score highly on these characteristics. However, Study 2 addressed this by only recruiting frequent consumers and the experimental groups were matched on all measured variables. In terms of other limitations, participants were mostly British, with an overweight BMI. Therefore, the findings of this study cannot be generalized to other ethnicities, ages or more extreme BMI groups. The sample recruited was a university staff and student population who would have a higher than average level of education. Future research should recruit other sociodemographic groups to consider the generalisability of the current findings. This was a short term-study conducted in a laboratory context, therefore further research should establish the longer-term effects of whether LCS beverages are sufficient in satisfying hedonic eating motivations in real-world settings.

## Conclusion

LCS beverages did not consistently protect consumers from craving-induced increases in food intake. However, frequent consumers consumed fewer calories overall when LCS beverages were available (relative to unavailable), as well as experiencing more control over their food intake, greater meal enjoyment and less guilt. These findings provide novel insight into the psychological mechanisms underpinning frequent consumption of LCS beverages in the context of their positive effect on weight, as has been shown elsewhere in the literature (Rogers et al., 2016).

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## Study 1 Supplementary Analysis

## Study 1 Methods

### Attentional bias data analysis

Eye-tracker: Participants were seated approximately 23 inches away from the computer screen with their chin on a chin-rest. A 9-point calibration with a validation procedure was carried out prior to the visual probe paradigm. Participants did not make any fixations on the pictures on 11.2% of trials in the task.

#### *Attentional bias scores*

Manual response to latencies probes**:** Data from practice and filler trials were discarded. Reaction times faster than 200ms, slower than 2000ms and then three standard deviations above the individual mean were removed prior to analysis (see Schoenmakers, Weirs & Field, 2008). Attentional bias scores were determined by computing mean reaction times to congruent probes (those that appeared in the same location as LCS beverage images) and incongruent probes [those that appeared in the same location as control (water or SSB) images] before subtracting the congruent from incongruent reaction times. Two separate bias scores were computed– for LCS beverages compared to water, and for LCS beverages compared to SSB. A positive score indicated increased attention towards LCS beverages, while a negative score indicated an attentional bias towards the control (i.e. water or SSB) images.

## Eating behaviour questionnaires

*Dietary restraint, emotional and external eating*: The Dutch Eating Behaviour Questionnaire (DEBQ, Van Strien et al., 1986) was used to assess dietary restraint, emotional and external eating on a 33-item scale. Participants were asked how frequently each of these statements applies to them on a 5-part likert scale, such as "Do you try to eat less at mealtimes than you would like to eat?". All responses are scored on a 5-point Likert scale from "Never" to "Very Often". Participant's level of restraint was determined by the mean score of the individual items.

*Trait chocolate craving:* The Attitudes to Chocolate Questionnaire (ACQ, Benton et al., 1998) was used to assess craving for chocolate and eating chocolate for emotional reasons (craving), negative feelings associated with eating chocolate (guilt), and eating chocolate for functional reasons (functional) on a 24-item scale. Responses were recorded on a 100mm VAS ranging from "Not at all like" to "Very much like me".

*Disinhibition:* Participants completed the 'Disinhibition' sub-scale of the Three Factor Eating Questionnaire (TFEQ) (Stunkard & Messick, 1985). Disinhibition refers to the general tendency to overeat. The TFEQ-D sub-scale consists of 16 items such as "I usually eat too much at social occasions like parties and picnics".

## Data analysis

### *Craving manipulation*

A 2 (condition: craving exposure/control) x 2(consumer group; Frequent/non-consumers) x 5 (time) mixed design ANOVA was conducted with condition and consumer group as the between-subjects factors, time as the within-subjects factor and craving (VAS) as the dependent variable.

### *Attentional bias scores*

Reaction time bias: A 2 (condition; craving vs control) x 2 (consumer group; freq. vs. non-consumers) ANOVA was conducted with condition and consumer group as between-subjects factors and response latency bias for LCS beverages relative to water as the dependent variable. The analysis was then repeated with response latency bias for LCS beverages relative to SSB as the dependent variable.

## Study 1 Results

### Craving manipulation

The ANOVA revealed a significant main effect of condition on craving for chocolate, $F(1,116)=44.12$, $p<.001$ $\eta_p^2=.28$, and a condition x time interaction, $F(2.24,260.15)=47.44$, $p<.001$ $\eta_p^2=.29$ (see Fig. S1). Planned comparisons using t-tests revealed participants in the craving condition reported significantly higher craving for chocolate at time-points T2 ($p<.001$; following craving exposure), T3 ($p<.001$; following craving booster) and T4 (p<.001; end of VPT) relative to the control condition. Importantly, there was no difference between conditions at T1 or T5 (*ps*>.264). There was no main effect of consumer group, $F(1,116)=1.03$, $p=.313$, $\eta_p^2=.01$, and no interaction between condition x time x group, indicating that the effect of condition over time was consistent in frequent and non-consumers, $F(2.24,260.15)=.913$, $p=.412$, $n_p^2=.01$.

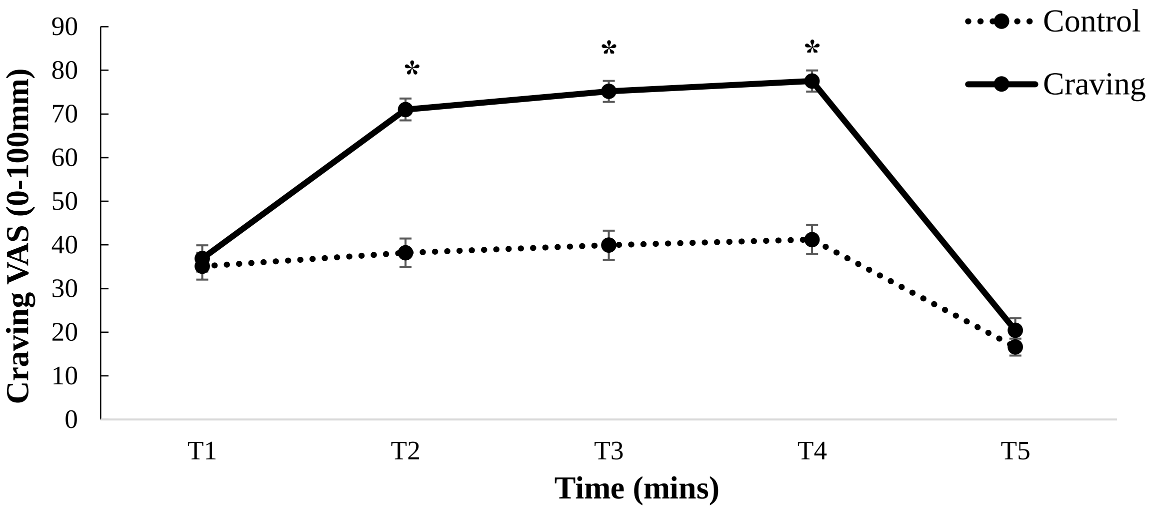


***Fig. S1.*** Ratings of craving for chocolate at each time-point in the craving and control condition conditions (collapsed across frequent and non-consumers). Values are means and standard errors of the mean. *$p<.001$

## Attentional bias

Reaction times: Inconsistent with Hypothesis 2, there were no main effects of consumer group or condition, and no condition x consumer-group interaction on response latency bias for LCS beverage-related images relative to water-related images, all *Fs* < 1.553, all *ps*>.215. Similarly, there were no main effects of consumer group or condition, and no condition x consumer-group interaction on response latency bias for LCS beverage-related images relative to SSB-related images, all *Fs* < 2.169, all *ps* > .143.

## Appetite ratings

A mixed ANOVA revealed a main effect of condition on hunger ratings, $F(1,116)=9.62$, $p=.002$, $\eta_p^2=.08$. There was also a condition x time interaction, $F(2.18, 253.28)=7.54$, $p<.001$, $\eta_p^2=.06$. Follow-up t-tests revealed that there was a significant difference in hunger levels between the craving and control conditions at T2 ($p<.001$; following first craving exposure), T3 ($p<.001$; mini-craving exposure) and T4 ($p<.001$; end of VPT). There was no significant difference between conditions at T1 and T5 (*ps*>.105). Furthermore, there was no main effect of group or interaction between condition x group x time indicating that the effect was consistent in frequent and non-consumers, (*ps*>.746).

There was a main effect of condition on fullness, $F(1,116)=5.69$, $p=.019$, $\eta_p^2=.05$, and a condition x time interaction, $F(1.58, 183.03)=5.01$, $p=.013$, $\eta_p^2=.04$. Follow-up t-tests showed that participants in the craving condition reported significantly lower fullness levels at time-point T2 ($p=.021$), T3 ($p=.003$) and T4 ($p<.001$) relative to the control condition. There was also no difference between conditions at T1 or T5 (*ps*>.120). Furthermore, there was no main effect of group or condition x group x time interaction for fullness ratings, (*ps*>.830).

There was no main effect of condition or condition x time on thirst ratings, (*ps*>.125). There was no main effect of consumer group, $F(1,116)=.505$, $p=.479$, $\eta p^2=.01$ but there was an interaction between consumer group x time on thirst ratings, $F(2.32, 268.73)=3.39$, $p=.029$,

$\eta_p^2$=.03. Frequent consumers had (marginally) higher thirst at T4 (*p*=.069) relative to non-consumers. Furthermore, there was no interaction between condition x group x time on thirst ratings, (*p*=.118).

## Study Results 2

### Craving manipulation

A mixed-ANOVA revealed a main effect of condition on craving for chocolate, $F(1,168)=51.08$, $p<.001$, $\eta_p^2=.23$, and a condition x time interaction, $F(2.25,378.92)=35.20$, $p<.001$, $\eta_p^2=.17$. Planned comparisons using t-tests revealed a significant difference in craving for chocolate between time-points T2 (*p*<.001; first craving exposure), T3 (*p*<.001; booster craving exposure), T4 (*p*<.001; end of VPT task) and T5 (*p*<.001; after food intake) but not at T1 (*p*=.078), indicating that the manipulation was successful. There was no main effect of group (*p*=.562) or interaction between condition x time x group, $F(2.25,378.92)=1.70$, $p=.179$, $\eta_p^2=.01$. This indicates that the effect of the craving manipulation over time was consistent in the LCS available and LCS unavailable groups (Fig.S2).

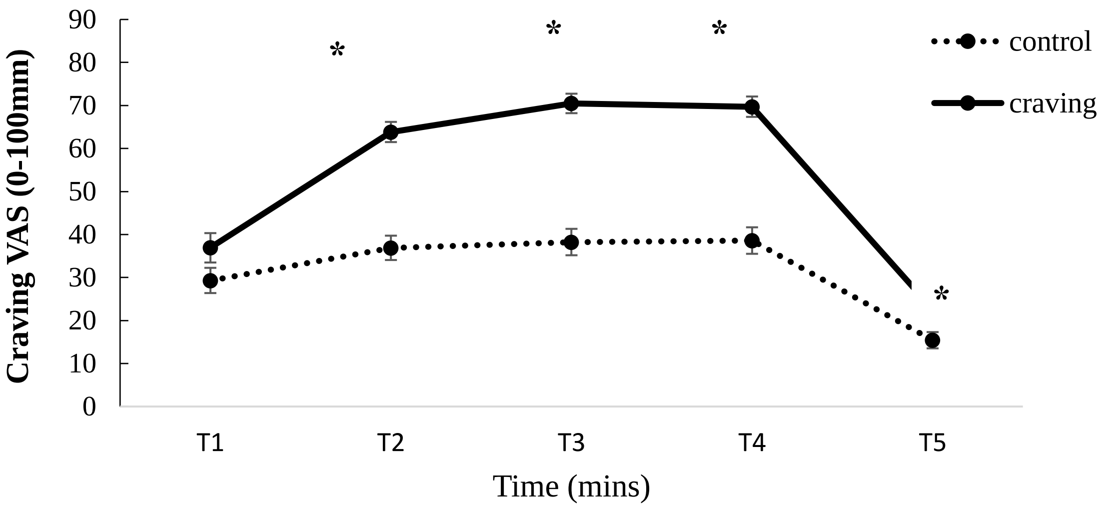


***Fig. S2*** Ratings of craving for chocolate at each time-point in the craving and control condition conditions for both LCS available and LCS unavailable groups. Values are means and standard errors of the mean. *$p<.001$.

## Energy intake

The main analysis for energy intake is provided in the manuscript. Energy intake was further broken down to show the calories consumed from the food and beverage types in each condition separately (see Table S1 below). The results of the exploratory analyses to examine the effects of group (i.e. LCS available vs LCS unavailable) on intake of specific food-types (i.e. sweet foods, savoury foods, beverages) are reported in the main manuscript file.

**Table S1.** *Energy intake from food type by consumer group. Values are means with standard deviations in parentheses*

| **Condition** | **Sweet foods (kcal)** | **Savoury (kcal)** | **Beverages (kcal)** | **Total (kcal)** |
|---|---|---|---|---|
| LCS beverage available; Craving | 301.97 (234.15) | 289.98 (296.35) | 1.13 (.44) | 593.08 (404.14) |
| LCS beverage available; Control | 240.28 (302.91) | 199.12 (196.10) | 1.11 (.40) | 440.51 (353.63) |
| LCS beverage unavailable; Craving | 359.92 (183.66) | 327.70 (284.42) | 23.35 (40.89) | 710.97 (368.48) |
| LCS beverage unavailable; Control | 289.47 (178.62) | 284.42 (209.29) | 10.78 (27.16) | 584.72 281.77) |

## Appetite ratings

There was a main effect of condition on hunger, $F(1,168)=9.23$, $p=.003$, $\eta_p^2=.05$ and a condition x time interaction, $F(3.14, 527.28)=6.24$, $p<.001$, $\eta_p^2=.04$. Follow-up t-tests revealed that participants in the craving condition reported significantly higher hunger levels at time-point T2 ($p<.001$), T3 ($p<.001$) and T4 ($p=.003$) relative to the control condition. Importantly, there was no difference between conditions at T1 or T5 (*ps*>.439). There was no main effect of group and no group x condition interaction (both *ps*>.776). There was also no group x condition x time interaction ($p=.476$), indicating that the effect of condition over time was consistent in LCS available and the LCS unavailable groups.

Similarly, there was a main effect of condition on fullness, $F(1,168)=8.09$, $p=.01$, $\eta p^2=.05$; fullness was lower in the craving condition relative to the control. However there was no significant condition x time interaction, $F(1.86, 312.22)=2.01$, $p=.140$, $\eta_p^2=.01$. There was no main effect of group or group x condition interaction (both *ps*>.862). Additionally, there was no group x condition x time interaction *(p*=.381).

There was a main effect of condition on thirst ratings, $F(1,168)=5.02$, $p=.026$, $\eta_p^2=.03$ and condition x time interaction, $F(2.64, 444.10)=13.62$, $p<.001$, $\eta_p^2=.08$. Follow-up t-tests revealed participants in the craving condition reported significantly higher thirst levels at time-point T3 ($p=.022$) and T4 ($p<.001$), relative to the control condition. There was no difference between conditions at T1, T2 or T5 (*ps*>.271). There was no main effect of group or group x condition interaction, (*ps*>.654) or group x condition x time interaction ($p=.477$).

## Attentional bias

Two separate ANOVAs were conducted to look at attentional bias towards LCS beverage-related images in relation to water and SSB related images, respectively. Results showed no main effects of condition or group on response latency bias for LCS beverages-related images relative to water-related images, *Fs* <.248, all *ps*>.619. There was also no condition x group interaction on response latency bias for LCS beverage-related images relative to water-related image, $F(1,168)=.248$, $p=.619$, $\eta_p^2<.01$. Similarly, there were no main effects of condition or group on response latency bias for LCS beverage-related images relative to SSB-related images, all *Fs* < .029, all *ps*>.865. There was also no condition x group interaction on response latency bias for LCS beverage-related images relative to SSB-related images, $F(1,168)=.03$, $p=.865$, $\eta_p^2<.01$.