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Additive effects of sensory-enhanced satiety and memory for recent eating on appetite.

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Short title: Combined effects of sensory and memory on appetite

Abstract

The sensory characteristics of a product have been shown to interact with actual nutrient content to generate satiety. Separately, cued recall of recent eating has also been shown to reduce food intake. Here we explore for the first time how these two effects interact, with the hypothesis that sensory enhancement of satiety might be mediated by more vivid memory of the earlier consumed item. On each of two test sessions, 119 women volunteers consumed a control drink (lemonade) on one morning and then one of two test drinks on the next day 30 minutes before an ad libitum lunch. The test drinks were equicaloric but one was noticeably thicker and creamier, and expected to generate stronger satiety. Just prior to the test lunch, participants were asked to recall either the test drink (test recall) or the drink from the previous day (control recall). Overall, lunch intake was significantly lower after the thicker and creamier (enhanced sensory ES) than thinner (low sensory: LS) test drink ($p<0.001$, $\eta^2 = 0.11$) regardless of recall condition ($p=0.65$, $\eta^2 < 0.01$), but was significantly lower after the test than control recall condition ($p<0.001$, $\eta^2 = 0.14$). Rated hunger was lower after consuming the ES than LS drink both immediately after consumption ($p<0.001$, $\eta^2 = 0.11$) and prior to the test lunch ($p=0.007$, $\eta^2 = 0.06$), while rated hunger just before lunch tended to be lower after recalling the test than control drink ($p=0.052$, $\eta^2 = 0.03$) regardless of the sensory characteristics ($p=0.27$, $\eta^2 = 0.01$). Overall these data further demonstrate the power of ‘sensory-enhanced satiety’ and cued recall of earlier eating as methods to reduce acute food intake, but suggest these effects operate independently.

Introduction

How much is consumed at any one eating event (meal) is determined by a complex interplay between cognitive, sensory and physiological influences. Some of these influences arise from what was consumed recently: how much is consumed at one meal influences how much is consumed at subsequent meals.

The widely used preload-satiety test, where the effects of manipulations of the characteristics of one meal (the preload) are tested through the subsequent experience of appetite and food intake at the next meal or meals (see Almiron-Roig, et al., 2013 ; Benelam, 2009 for reviews), has provided evidence that many factors including the form (e.g. solid vs liquid: Flood-Obbagy & Rolls, 2009; Hulshof, de Graaf, & Weststrate, 1993; Mattes & Campbell, 2009), overall energy density and/or volume (e.g. De Graaf & Hulshof, 1996; Gray, French, Robinson, & Yeomans, 2002; Rolls, Bell, & Waugh, 2000), macronutrient content (e.g. Astbury, Stevenson, Morris, Taylor, & Macdonald, 2010; Bertenshaw, Lluch, & Yeomans, 2008; De Graaf, Hulshof, Weststrate, & Jas, 1992; Poppitt, McCormack, & Buffenstein, 1998; Rolls, et al., 1994; Yeomans, Lee, Gray, & French, 2001) and sensory characteristics (Cassady, Considine, & Mattes, 2012; Chambers, Ells, & Yeomans, 2013; Yeomans & Chambers, 2011) of the preload all contribute to the subsequent experience of appetite. But more recently research has also shown the importance of memory in appetite control, whereby experimentally prompting recall of an earlier eating event just prior to a subsequent test meal affects intake of that meal (Higgs, 2002; Higgs, 2008; Higgs & Donohoe, 2011; Higgs, Williamson, & Attwood, 2008). How these memory effects interact with more widely studied sensory-nutrient influences on satiety, however, remains relatively unexplored.

A classic puzzle in the satiety literature is how the same nutrients consumed in different forms/contexts can have strikingly different effects on appetite. The classic contrast is between liquid and solid food: when matched for energy content, nutrients consumed as beverages typically generate weaker satiety than the equivalent amount of energy consumed in solid form (e.g. Flood-Obbagy & Rolls, 2009; Mattes, 2006; Tsuchiya, Almiron-Roig, Lluch, Guyonnet, & Drewnowski, 2006), although soups stand out as unusual in often being particularly satiating (Flood & Rolls, 2007; Mattes, 2005; Spiegel, Kaplan, Alavi, Kim, & Tse, 1994).

There is increasing evidence that these differences may be explained, at least in part, as a consequence of differences in beliefs and expectations about the ingested product (Brunstrom, Brown, Hinton, Rogers, & Fay, 2011; Lett, Norton, & Yeomans, 2016; McCrickerd, Chambers, & Yeomans, 2014b). A striking example was a study which showed differences in both behavioural and physiological measures of satiety in people who consumed the same nutrients either as a liquid or solid (jelly) format and who had been persuaded either that the ingested product would be liquid or solid in their stomach, even though in all cases the ingested food would have been liquid once ingested (Cassady, et al., 2012). Notably, participants evidenced stronger satiety when the ingested food was experienced orally as a solid versus liquid, and also when they believed the ingested food would be solid rather than liquid in the stomach. These, and other data, support a model of satiety that suggests that sensory and cognitive factors at the time of ingestion modify the actual post-ingestive experience of ingested nutrients, offering novel approaches for the optimisation of satiety in product development (Chambers, McCrickerd, & Yeomans, 2015).

Building on earlier work which suggested that the apparent enhanced satiating effects of protein might be in part mediated by the sensory characteristics associated with the presence of protein (Bertenshaw, Lluch, & Yeomans, 2013), possibly through an effect of umami taste (Masic & Yeomans, 2014), a series of studies explored how manipulations of the sensory characteristics of the ingested preload interacted with actual nutrient content to generate satiety. In these studies, smoothie drinks were developed which had a thicker texture and creamier flavour (ES) than the LS versions (McCrickerd, Chambers, Brunstrom, & Yeomans, 2012; McCrickerd, Chambers, & Yeomans, 2014a; McCrickerd, et al., 2014b; Yeomans & Chambers, 2011; Yeomans, McCrickerd, Brunstrom, & Chambers, 2014). Thickness and creaminess were manipulated since these types of cues are often found in foods and drinks with higher energy content, and have been shown to be associated with higher satiety expectations (Lett, Yeomans, Norton, & Norton, 2015; McCrickerd, Lensing, & Yeomans, 2015). These sensory manipulations were then combined with manipulations of nutrient content (by addition of the non-sweet carbohydrate maltodextrin) to yield lower (typically c. 80kcal) or higher (c. 280kcal) versions. The key and consistent finding was greater satiety, evidenced by enhanced fullness, reduced hunger and reduced subsequent test-meal intake following consumption of the ES higher energy drinks compared to the same energy in LS versions (Chambers, et al., 2013; McCrickerd, et al., 2014b; Yeomans, Re, Wickham, Lundholm, & Chambers, 2016; Yeomans & Chambers, 2011; Yeomans, et al., 2014). These results have since been interpreted in terms of sensory-enhanced satiety, the idea that expectations about satiety generated by sensory cues modify actual satiety responses to ingested nutrients (Chambers, et al., 2015).

How then might these sensory cues act to enhance satiety? One possibility is that the associated satiety-related expectations generate preparatory physiological responses, including anticipatory release of satiety hormones, and these then lead to an enhanced satiety response. The idea that cues associated with nutrient ingestion lead to learned preparatory physiological responses is far from new: the idea of cephalic phase responses was inspired by Pavlov's seminal work on food-related conditioned responses, and has been discussed widely (Smeets, Erkner, & de Graaf, 2010; Woods, 1991). What is different about the enhanced-satiety idea is that such responses can be stimulated by top-down explicit expectations rather than more basic stimulus-response associations. This view is supported by the study by Cassady and colleagues discussed earlier (Cassady, et al., 2012), and by recent data from our laboratory showing greater release of the satiety-related hormones pancreatic polypeptide and cholecystokinin after consumption of the ES higher-energy versions of the test drinks (Yeomans, et al., 2016).

Sensory cues may also exert effects on satiety through activation of other cognitive processes, such as memory. In an elegant series of studies, Higgs and colleagues have shown that explicitly asking participants to recall the specific details of an eating event preceding a test meal, relative to eating events on other days, lead to a decrease in food intake at that test meal (Higgs, 2002; Higgs, 2008; Higgs & Donohoe, 2011; Higgs, et al., 2008). The implication is that stronger memories for earlier eating events act to reduce subsequent food intake. The idea that memory plays a role in appetite control is consistent with clear evidence that disruptions to key brain areas involving memory leads to both forgetting to eat and forgetting that one has eaten (Rozin, Dow, Moscovitch, & Rajaram, 1998). Notably, distraction during eating has been shown to reduce subsequent accuracy of recall for how much was consumed (Higgs & Woodward, 2009; Mittal, Stevenson, Oaten, & Miller, 2011), while deliberately focusing on eating enhanced subsequent recall (Higgs & Donohoe, 2011).

The effects of cued memory on intake offer a potential alternative explanation for the sensory-enhancement of satiety. If a food generates stronger satiety expectations at the point of consumption, the greater relevance of those expectations to intake may make that food more memorable. This enhanced memory might then plausibly contribute to reduced intake at the next meal. If the effects of sensory-enhancement operate through memory in this way, then explicitly asking people to recall the sensory characteristics of these drinks prior to a lunch test would be predicted to lead to greater satiety. To test this, we contrasted the satiating effects of two equicaloric drinks, one a standard (low sensory, LS) version and the second an ES version based on the manipulations in our recent studies (McCrickerd, et al., 2012; McCrickerd, et al., 2014b). These drinks were consumed in one of two memory conditions: a test recall (TR) condition where they were explicitly asked to recall the characteristics of the consumed preload one hour later, just before the start of a lunch intake test, and a control recall (CR) condition where they recalled a drink consumed the previous day. If sensory-enhanced satiety involves memory processes then recalling the ES version of the drink (the sensory characteristics of which have been shown to be perceived as filling) before a test meal should lead to a greater reduction in intake than would recalling a drink which generates lower satiety expectations or a control condition where neither drink is specifically recalled.

Materials and Methods

Design

The study used a between-participants design to contrast the satiating effects of equicaloric ES and LS preload drinks consumed mid-morning with or without a task administered immediately before lunch which was designed to enhance the memory of the preload drink's sensory characteristics (test recall, TR vs. recall of the control drink consumed on the previous day, CR). Outcome measures were intake at the test lunch consumed one hour after the memory test and ratings of appetite before and after both the preload drink and test meal.

Participants

One hundred and nineteen healthy female volunteers participated, mainly students at the University of Sussex. Since the prediction was an interaction, sample power calculations were complex. We first calculated the number of participants needed to replicate the difference in intake between ES and LS conditions based on our earlier findings (Yeomans, et al., 2014): assuming the effect size for the equivalent conditions and power of 0.8, this indicated n=23 would be needed. No study has examined effects of memory on lunch intake, but based on previous snack intake data (Higgs, et al., 2008) we predicted a 20% decrease in intake in TR relative to CR conditions: using lunch intake data from studies using between-participants contrasts in our lab (McCrickerd, et al., 2014b; Yeomans, et al., 2014) and power of 0.8, analysis suggested that n = 20 would be sufficient to detect a main effect of the memory manipulation. However, the key prediction was that intake in the ES/TR condition would be suppressed more than by the added effects of sensory and memory effects combined. Assuming that memory caused an additional 20% reduction beyond the effects of sensory, we calculated n=31 would be needed, and consequently targeted a minimum sample of 30 in each of the four conditions. Potential participants were invited to participate in a study “To investigate how memory affects appetite.” by a combination of emails to participant pools, adverts and personal contacts. The memory cover story justified the actual memory test while disguising the true purpose of the study. Since the study involved ingestion, those who were diabetic, had been diagnosed with an eating disorder, were taking prescription medicine (other than contraceptives), who had an aversion or allergy to any of the foods and ingredients used in the study or who smoked were excluded. Participants were assigned at random to one of four test conditions, combining the two sensory (ES or LS) and memory (TR or CR) conditions. These four groups did not differ significantly in age, BMI or dietary restraint measured using the Three Factor Eating Questionnaire (TFEQ: Stunkard & Messick, 1985: see Table 1). The study protocol was approved by the University of Sussex Sciences & Technology Cross-Schools Research Ethics Committee and complied fully with British Psychological Society ethical guidelines.

Test food and drinks

Breakfast (total 401kcal), provided to ensure that participants began the test part of the experiment in comparable motivational states, consisted of cereal (60g: Crunchy Nut cornflakes, Kellogg’s plc UK), semi skimmed milk (160g: Sainsbury's, UK) and orange juice (200g: Sainsbury's plc, UK).

The mid-morning preloads were two versions of a fruit-yoghurt based smoothie drink prepared in the Ingestive Behaviour Unit at the University of Sussex, either LS or ES, based on drinks used previously in research from the Sussex Ingestive Behaviour Unit (McCrickerd, et al., 2012; McCrickerd, et al., 2014a; McCrickerd, et al., 2014b; Yeomans & Chambers, 2011; Yeomans, et al., 2014). Each serving of the LS version combined a commercial fruit juice (100g: mango, peach and papaya juice, Tropicana, UK) 0% fat fromage frais (30g: Sainsbury's plc, UK), a low calorie commercial fruit squash (35g: peach and barley squash, Robinson's, UK), water (100g) and maltodextrin (55g: C*PUR 1910, Cargill, UK). Thickness and creaminess of the ES version were enhanced by addition of 1g of tara gum (Kalys Gastronomie, France), 0.5g of milk caramel flavour (Synrise, Denmark) and 1g of vanilla extract (Nielsen-Massey, UK). These manipulations have been shown to increase satiety expectations (McCrickerd, et al., 2012; McCrickerd, et al., 2014b) and reduce subsequent appetite and intake in preload-satiety tests (Chambers, et al., 2013; Yeomans, et al., 2016; Yeomans & Chambers, 2011). The two drinks provided 274kcal in the 320g served portion. An additional drink, 320g of cloudy lemonade (Sainsbury's, UK), consumed on the day prior to the test lunch day, acted as the control for the memory manipulation.

The satiety test included an *ad libitum* lunch consisting of pasta (each serving 250 grams of cooked pasta, "Conchiglie", Sainsbury's UK, plus 250 grams of tomato and basil pasta sauce, Sainsbury's, UK). Participants were permitted to consume water *ad libitum* during this meal.

Procedure

Participants attended the Ingestive Behaviour Unit at the University of Sussex on two consecutive weekdays. On the first day, participants completed their informed consent and consumed the control drink at a pre-arranged time between 11.00 and 13.00h. On the second day, participants arrived for breakfast at a scheduled time between 8.30 and 10.00, having only consumed water from 23:00 the night before, and were required to consume all of the breakfast. They were instructed to return to the lab 2 hours later for the preload session, and were to refrain from eating and to drink only water during this time.

On the following day when the preload was consumed prior to the test lunch, participants were taken to a testing cubicle where they completed a standard set of ratings of appetite and mood administered using Sussex Ingestion Pattern Monitor software (SIPM Yeomans, 2000). Ratings were made using computerised visual analogue scales (VAS), with the question format 'How <descriptor> do you feel right now?' and end anchors "Not at all" (scored 0) and "Extremely" (scored 100). The ratings of interest were for "hungry" and "full", and these were embedded amongst other distracter mood questions: 'happy', 'anxious', 'clear-headed', 'calm', 'energetic', 'nauseous', 'tired', 'alert' 'thirsty' and 'headachy'. The rating order was randomised. Participants were then instructed to take a single mouthful of their preload drink, after which they completed VAS ratings of how 'thick', 'sweet', 'fruity', 'creamy', 'familiar', 'filling' and 'pleasant' they found that drink, phrased as 'How <descriptor> is the fruit yoghurt drink?'. They were then required to consume the preload drink in full, and then repeat the appetite and mood ratings. Participants then only consumed water between the preload and lunch test.

The lunch session started with the memory manipulation: participants were instructed to recall the specific characteristics of either the drink they had consumed that morning (i.e. the LS or ES preload) (TR condition) or the previous day (i.e. the cloudy lemonade, CR condition). They completed this task by first writing a description of the drink and then by rating how pleasant, thick, sweet, filling, thirst-quenching, creamy, tasty, cold and refreshing the drink was (in that order), using 100mm paper VAS end anchored "Not at all" and

"Extremely". Once completed, they repeated the appetite and mood ratings using SIPM. They were then served a sample of their pasta lunch to taste and evaluate to assess the appetising effects of food presentation (Yeomans, 1996). Participants were asked 'How <descriptor> is the pasta?' with ratings of 'savoury', 'familiar', 'pleasant' and 'salty', followed by ratings of hungry and full immediately afterwards, after which they were served 500g of the pasta lunch and were told to eat as little or as much as they liked. A digital balance (Sartorius model BP4200) disguised by a placemat and linked to a PC running the SIPM software recorded the weight remaining throughout the meal to record intake. Once at least 400g of pasta had been consumed, participants were prompted to call the researcher to get a new serving in order to prevent portion-size cues determining meal termination. After they had eaten as much lunch at they wanted, the participants rated their appetite and mood for the final time. Participants then completed the TFEQ so that potential confounding effects of restraint could be controlled for in analyses. Height (m) and weight (kg) were measured in order to calculate their BMI and participants were debriefed, with the researcher explaining the true nature of the study. They were then paid £15 and thanked for taking part.

Data analysis

Principle interest was in changes in appetite and food intake at the test lunch as a consequence of the memory and sensory manipulations. To test this, intake (g) was contrasted between conditions with sensory (LS or ES) and memory (TR or CR) as conditions using between-participants ANOVA. For appetite, participants completed hunger and fullness ratings on five occasions: before and after the preload drink and three ratings at lunchtime: prior to food being presented (Pre-lunch), on tasting food (Post-taste) and at the end of lunch (Post-lunch). Therefore, 3-way ANOVA was used to contrast both ratings between the five rating times (within-participant) and depending on the sensory and memory conditions (between-participants). To test whether the sensory manipulation was effective, the sensory ratings made at the start of the preload test were also contrasted depending on sensory and memory conditions using between-participants ANOVA. All rating data from the lunchtime test for one participant were lost due to computer failure.

Results

Lunch intake

Overall, as can be seen in Figure 1, participants ate less after the ES than LS preload [$F(1,115) = 13.88$, $p<0.001$, $\eta^2 = 0.11$] and in the TR than CR memory condition [$F(1,115) = 18.84$, $p<0.001$, $\eta^2 = 0.14$] but the sensory x memory interaction was not significant [$F(1,115) = 0.21$, $p=0.65$, $\eta^2 < 0.01$].

Rated hunger

Hunger ratings are shown in Figure 2a. ANOVA revealed a significant two-way interaction between time x sensory [$F(4,456) = 5.49$, $p<0.001$, $\eta^2 = 0.05$] and a marginally non-significant time x memory interaction [$F(4,456) = 2.08$, $p=0.086$, $\eta^2 = 0.02$], as well as significant overall main effects of time [$F(4,456) = 243.46$, $p<0.001$, $\eta^2 = 0.68$] and sensory [$F(1,114) = 6.07$, $p=0.015$, $\eta^2 = 0.05$], but not memory [$F(1,114) = 2.12$, $p=0.15$, $\eta^2 = 0.02$]. Given the significant interactions with time, follow-up analyses contrasted ratings at each time depending on the sensory and memory conditions using two-way ANOVA, with the predicted sensory x memory interaction the critical test.

Rated hunger prior to the preload did not differ significantly between conditions, confirming that there were no spurious group differences. Hunger immediately after consuming the preload was significantly lower after consuming the ES than LS drink, in line with the predicted effects of the sensory manipulation [$F(1,114) = 13.63$, $p<0.001$, $\eta^2 = 0.11$], but there was no significant main effect of memory or sensory x memory interaction (which was not relevant at that time). The significant effect of the sensory manipulation on rated hunger was still evident at Pre-lunch (following the memory task) [$F(1,114) = 7.53$, $p=0.007$,

$\eta^2 = 0.06$], and now hunger tended to be lower in the TR than CR condition [$F(1,114) = 3.85$, $p=0.052$, $\eta^2 = 0.03$], but the key interaction was not significant [$F(1,114) = 1.22$, $p=0.27$, $\eta^2 = 0.01$]. Hunger after the test lunch was first tasted (Post-taste), which tends to be a better predictor of actual intake than does rated hunger in the absence of knowledge of the food to be consumed (Yeomans & Bertenshaw, 2008), was also significantly lower in the ES than LS conditions [$F(1,114) = 4.49$, $p=0.036$, $\eta^2 = 0.04$], and was also significantly lower in the TR than CR condition [$F(1,114) = 4.10$, $p=0.045$, $\eta^2 = 0.04$], again with no significant interaction [$F(1,114) = 1.21$, $p=0.27$, $\eta^2 = 0.01$]. Hunger after tasting the lunch also increased slightly, but significantly, overall (by 4±1 VAS units: $t(117) = 2.98$, $p=0.002$) in line with an appetizing effect of the test lunch. There was no significant effects of sensory [$F(1,114) = 0.01$, $p=0.98$, $\eta^2 < 0.01$] or memory [$F(1,114) = 0.25$, $p=0.62$, $\eta^2 < 0.01$] manipulations on hunger at the end of the meal, which was similarly low in all conditions despite the differences in actual intake.

Rated fullness

Analysis of rated fullness revealed a slightly different pattern to that seen with hunger: when all data were included, the only significant effects were an interaction between sensory and time [$F(4,456) = 7.37$, $p<0.001$, $\eta^2 = 0.06$], and notably the memory x time interaction that was significant for hunger was not significant for fullness [$F(4,456) = 0.67$, $p=0.62$, $\eta^2 < 0.01$]. There was also the expected main effect of time [$F(4,456) = 220.08$, $p<0.001$, $\eta^2 = 0.66$] and a significant main effect of sensory [$F(1,114) = 7.67$, $p=0.007$, $\eta^2 = 0.06$] but no significant main effect of memory [$F(1,114) = 0.24$, $p=0.63$, $\eta^2 <0.01$]. As can be seen (Figure 2B), fullness was similar in all conditions prior to preload consumption, and then increased more after the ES than LS preload, and remained higher after ES into the lunch test. This was confirmed from analysis of each time point individually: at Post-preload, Pre-lunch and Post-taste, there were significant effects of sensory (Post-drink $F(1,115) = 8.51$, $p=0.004$, $\eta^2 = 0.07$: Pre-lunch $F(1,115) = 8.93$, $p=0.003$, $\eta^2 = 0.07$: Post-taste $F(1,115) =12.12$, $p<0.001$, $\eta^2 = 0.10$), with higher fullness in ES than LS conditions throughout, but no significant main effect of memory (Post-drink $F(1,115) = 0.20$, $p=0.65$, $\eta^2 < 0.01$: Pre-lunch $F(1,115) = 0.37$, $p=0.54$, $\eta^2 < 0.01$: Post-taste $F(1,115) =0.95$, $p=0.33$, < 0.01) or memory x sensory interactions (Post-drink $F(1,115) = 0.25$, $p=0.65$, $\eta^2 < 0.01$: Pre-lunch $F(1,115) = 0.02$, $p=0.89$, $\eta^2 < 0.01$: Post-taste $F(1,115) = 0.07$, $p=0.79$, < 0.01) at any of these times. As with hunger, there were no significant differences between conditions at the end of the test meal.

Manipulation checks

The sensory manipulation relied on small but perceivable differences in sensory characteristics of the test preload drinks. Analysis of sensory ratings taken when these drinks were tasted confirmed this was so (Table 2). Thus, in line with our previous studies (McCrickerd, et al., 2012; McCrickerd, et al., 2014a; Yeomans, et al., 2014), the ES drink was rated as significantly creamier [$F(1,115) = 24.32$, $p<0.001$, $\eta^2 = 0.18$], thicker [$F(1,115) = 13.98$, $p<0.001$, $\eta^2 = 0.11$] and more filling [$F(1,115) = 8.37$, $p=0.005$, $\eta^2 = 0.07$] than was the LS drink, while the two drinks were well matched in sweetness, pleasantness and familiarity, with no significant differences between ES and LS versions. The memory condition was irrelevant at the time when the drinks were rated, and analysis confirmed there were no spurious effects of memory on any of these ratings.

The manipulation check for the memory manipulation came from what participants wrote during the memory procedure. All 119 participants correctly recalled either the lemonade drink if they were in the CR condition or the smoothie in the TR condition. We could also examine how well they recalled the specific characteristics of the LS and ES drinks from their ratings during the recall test: the rated thickness (ES 65±4, LS 49±5: $t(57) = 2.70$, $p=0.009$) and creaminess (ES 72 ± 2, LS 46 ± 5: $t(57) = 4.68$, $p<0.001$) was higher for the ES than LS drink during recall, although their memory for how filling the drinks did not differ significantly (ES 69±3, LS 62±5: $t(57) = 1.31$, $p=0.19$).

Discussion

The present study brought together for the first time two different short-term influences on control of food intake: the sensory experience of eating (Yeomans, 2015) and the memory of recent eating (see Robinson, et al., 2013 for review). The results provided very clear evidence that both the memory of recently consuming a drink and the drink's specific sensory characteristics had additive influences on subsequent satiety. This implies that memory effects on satiety may be working in parallel with sensory induced top-down regulation of gut satiety responses, rather than memory being the primary mechanism underlying sensory-enhanced satiety.

Previous studies of sensory-enhanced satiety have typically combined overt manipulations of a beverage's sensory characteristics with covert manipulation of its nutrient content, generating lower and higher energy versions (e.g. McCrickerd, et al., 2014b; Yeomans &

Chambers, 2011). Inclusion of low-energy versions in the present study, which because of the memory manipulation relied on a between-participants contrast, would have produced eight conditions and made the study unwieldy. However, it is notable that participants consumed less at lunch after the ES than LS versions of the drinks despite these being equicaloric, indicating that participants were better able to compensate for the drink's energy when its sensory characteristics predicted that it would be satiating (i.e. the ES version) in line with our previous research (reviewed in Chambers, et al., 2015). Lunch intake was lower by 72g on average following the ES drink compared to the LS version and this equated to 87Kcal lower energy intake, which is similar to the differences found in our earlier studies that included ES and LS low-energy controls (for example, 93kcal in Yeomans and Chambers, 2011).

The present study also confirmed that recalling recent consumption just prior to eating reliably reduces intake at the meal. To date, most studies examining these short-term effects of memory for recent eating on appetite have tended to manipulate recall of a large meal (typically pizza consumed at lunch) and measure effects on intake at a disguised snack intake test (Higgs, 2002; Higgs & Donohoe, 2011; Higgs, et al., 2008). In the present study the same basic design of directed recall of prior consumption just before an eating event was used, but notably the difference here was that the recalled item was snack-sized (a drink) consumed prior to a meal (lunch). That this simple memory enhancement of recent snacking was effective at reducing subsequent intake at lunch is notable since this implies that there is real scope for the use of prompted recall of prior snacking as an aid to moderating intake at subsequent meals.

The key idea behind this study was that participants would have stronger memories for ES than LS versions because of the expected impact of ES versions on their appetite. Thus we reasoned that combining the sensory and memory manipulations should result in lower intake in the combined ES/cued recall condition than seen with either manipulation alone. The present data suggest this is unlikely since the two manipulations had clear but additive effects on appetite, suggesting that sensory and memory cues that influence satiety operate independently. These findings should not be interpreted as definitive evidence for no role of memory in sensory-enhanced satiety, but do indicate that any such role of memory is not further enhanced by directed cued recall of the ingested drink. However, given recent evidence that manipulating the sensory characteristics of a product (to generate stronger expectations of satiety) leads to increased release of gut-based satiety hormone release (Yeomans, et al., 2016), at present the evidence suggests that sensory-enhanced satiety is more likely to operate through cued preparatory satiety responses than through memory-driven cognitive control of meal size. However, this does not preclude a role of higher cognitive processes in sensory-enhanced satiety, and our previous finding that the same food can vary in its effects on satiety depending on beliefs about the nature of that food (McCrickerd, et al., 2014b) supports a key role for top-down processes driven by beliefs about satiety in the sensory-enhanced satiety effect.

The present study tested the role of memory by asking whether manipulated sensory and cued memory interacted in their effects on intake. The conclusion that they do no interact is based on the lack of evidence for a statistical interaction. As this is drawing a conclusion based on a lack of significance, it is important to consider whether the study had adequate power to detect any putative interaction. Critically, we predicted a larger proportional decrease in intake in response to the sensory manipulation in the TR than CR memory condition: in practice, intake in the ES condition was reduced by 18% in the CR, and 21% in TR condition, a difference of just 3%. One approach to test whether this was a reliable non-significant finding was to apply Bayes theory (Dienes, 2014). Based on the predicted effect sizes used to make the power calculations, more was consumed in the key TR/ES condition than was predicted by an interaction. Calculation of the Bayes factor for that outcome resulted in a Bayes factor of 0.84, which supports an additive effect. However, even though we can be confident that there is no evidence of any interaction in these data, this does not preclude a role for memory in sensory-enhanced satiety. An alternative approach to this question could, for example, make use of the large variability in response to energy preloads to test whether a measure of the strength and characteristics of individual memory of the preload is a predictor of the satiety response.

The success of the present study relied on the success of the two main manipulations: changes to the sensory characteristic of the target pre-lunch drink to assess sensory influences on satiety, and the recall manipulation to assess cued memory. Manipulation checks confirmed both were effective. At the time of consumption, ES drinks were rated as thicker, more creamy and generated stronger expectations of satiety (i.e. were rated as more filling) than were LS drinks. Notably, these differences were strong enough to still be evident at the recall test, with the sub-group in the TR condition remembering the ES drink as significantly thicker and creamier, and tending to remember it as more filling, when recalling the drink just prior to lunch. For the memory test, the manipulation check demonstrated that the correct drink was recalled by all participants.

This study only looked at acute effects of the two key manipulations: how well these effects would be maintained with repeated consumption is less clear. With the sensory manipulation, two studies have examined the effects of repeated consumption on enhanced satiety in the ES condition (Hovard, et al., 2015; Yeomans, et al., 2014), and both studies found that satiating effect of ES versions was maintained following repeated consumption either in the laboratory or home setting. However, we are unaware of studies testing whether the effects of cued memory are sustained with repeated consumption, and if this approach was to be adapted as a component of behavioural programmes countering overeating then such studies are needed.

Overall, the present study further confirmed the robustness of sensory-enhanced satiety and cued-recall of recent eating as influences on short-term intake, and suggest these manipulations acted additively to reduce test lunch intake.

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Table 1. Characteristics of the participants in the four test groups. All data are mean ± SEM. TR: test recall; CR: control recall; ES: enhanced sensory; LS: low sensory; TFEQ: Three Factor Eating Questionnaire

	TR		CR	
	ES	LS	ES	LS
Age (years)	19.5 ± 0.8	21.0 ± 0.9	21.5 ± 0.7	20.4 ± 1.0
BMI (kg/m^2)	23.3 ± 0.4	22.7 ± 0.5	23.0 ± 0.3	23.7 ± 0.7
TFEQ Restraint	9.7 ± 1.1	9.4 ± 1.1	8.5 ± 1.1	9.2 ± 1.1

Table 2. Rated characteristics of the two test drinks (enhanced sensory, ES and low sensory, LS) in both memory conditions (Test TR or Control CR recall). Data are mean ± SEM visual analogue ratings on 100pt scales: in each row, data marked by different superscript letters differ significantly ($p<0.05$).

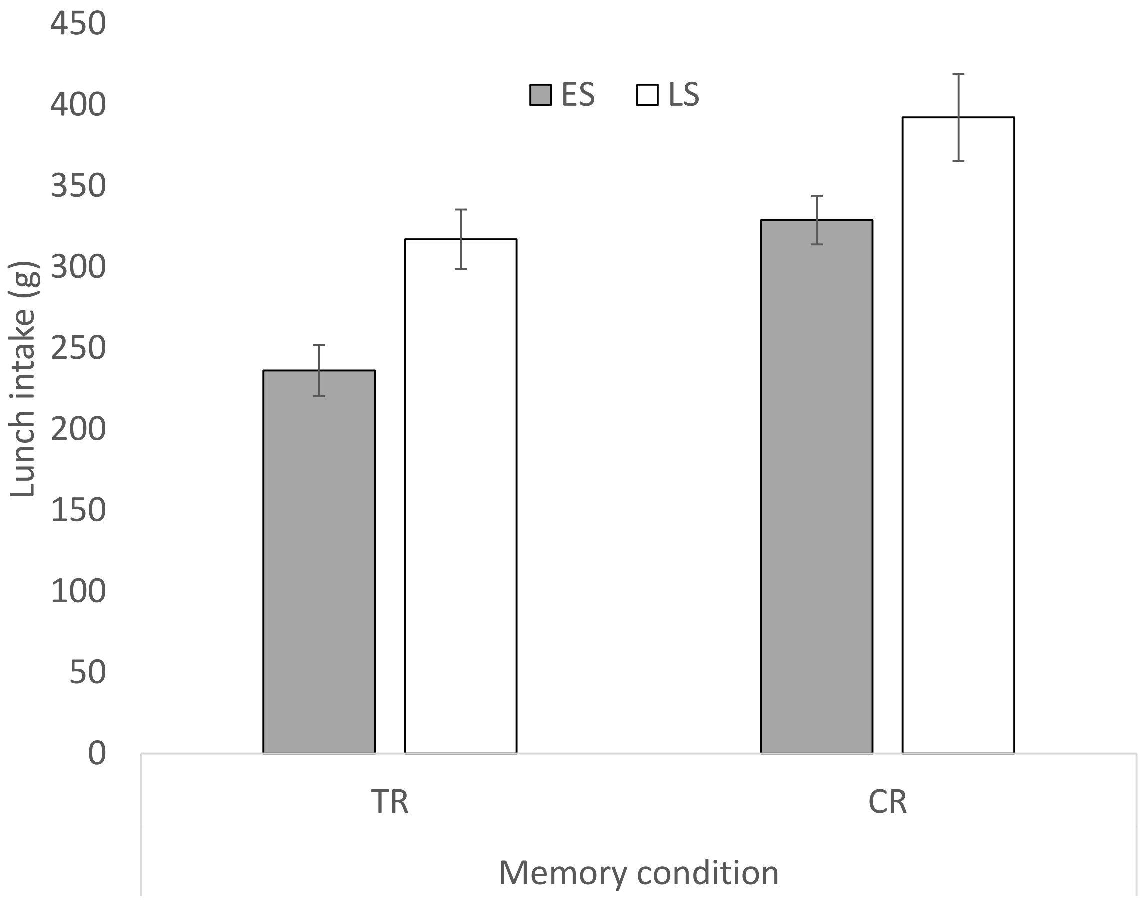
	TR		CR	
Rating	ES	LS	ES	LS
Creamy	66 ± 2^{a}	47 ± 4^{b}	67 ± 3^{a}	52 ± 4^{b}
Familiar	44 ± 5	56 ± 5	53 ± 5	52 ± 5
Filling	64 ± 4^{a}	54 ± 3^{b}	64 ± 3^{a}	55 ± 3^{b}
Pleasant	70 ± 3	74 ± 4	73 ± 4	69 ± 3
Sweet	66 ± 3	66 ± 3	75 ± 2	68 ± 3
Thick	66 ± 4^{a}	56 ± 4^{b}	68 ± 3^{a}	49 ± 4^{b}

Figure legends

Figure 1. Lunch intake depending on the memory recall condition (TR: recall of preload, CR recall of control drink) and drink preload sensory characteristics (ES: enhanced sensory; LS; low sensory). All data are mean ± SEM.

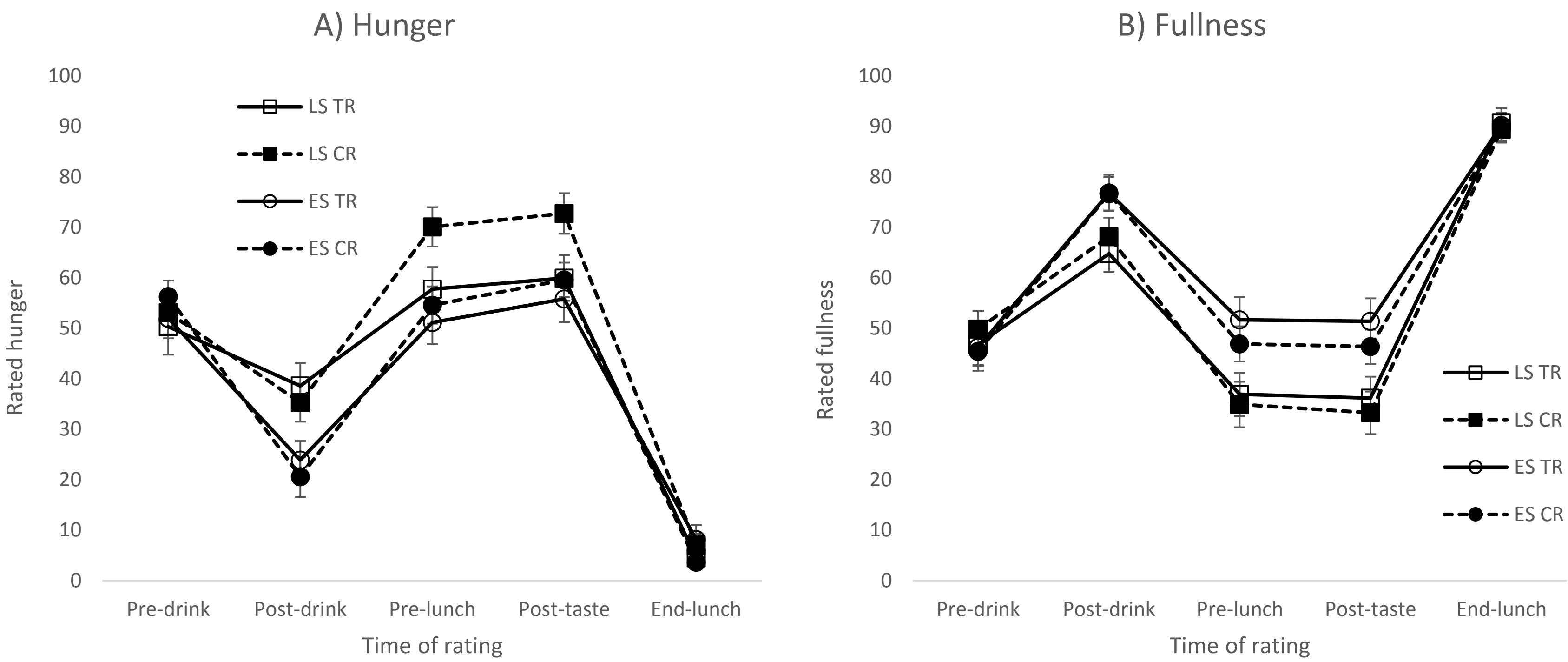
Figure 2. Rated (A) hunger and (B) fullness across the test session in the four treatment conditions: (—○—) enhanced sensory (ES) + recall preload (TR), (—□—) low sensory (LS) + TR, (--●--) ES + control recall (CR), (--■--) LS + CR. All data are mean ± SEM.

Figure 1



450
400
350
300
250
200
150
100
50
0
ES
LS
Lunch intake (g)
TR
CR
Memory condition

Figure 2


A) Hunger
Rated hunger
LS TR
LS CR
ES TR
ES CR
0
10
20
30
40
50
60
70
80
90
100
Pre-drink
Post-drink
Pre-lunch
Post-taste
End-lunch
Time of rating
B) Fullness
Rated fullness
LS TR
LS CR
ES TR
ES CR
0
10
20
30
40
50
60
70
80
90
100
Pre-drink
Post-drink
Pre-lunch
Post-taste
End-lunch
Time of rating