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

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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 min 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.

1. 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 & Donohoe, 2011; Higgs, 2002, 2008; 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

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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. 80 kcal) or higher (c. 280 kcal) 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, 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.

2. Materials and methods

2.1. 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.