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**The role of cognitive, sensory and nutrient  
interactions in satiation and satiety: considering  
consumers**

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Submitted for the degree of Doctor of Philosophy in Psychology

University of Sussex

School of Psychology

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## Declaration

The work in this thesis is presented in an ‘article format’ in which the middle chapters consist of discrete articles written in a style that is appropriate for publication in peer-reviewed journals in the field. The first and final chapters present synthetic overviews and discussion of the field and the research undertaken.

Paper 2 is published in the journal *Nutrition Bulletin* as:

Hovard, P., Chambers, L., Hull, S., Re, R., Wickham, M. S. J., & Yeomans, M. R. (2015). Sensory-enhanced beverages: effects on satiety following repeated consumption at home. *Nutrition Bulletin*, 40 (3), 187-198.

Paper 4 (incorporating two studies) is published in the journal *Flavour* as:

Hovard, P., & Yeomans, M. R. (2015). Assimilation of healthy and indulgent impressions from labelling influences fullness but not intake or sensory experience. *Flavour*, 4(1), 28.

Note that paper 4 is presented in the format required by the journal *Flavour* although references have been reverted to APA style.

Contributions from all authors are noted in the relevant chapters. The thesis author was responsible for the main study design, execution, analysis and manuscript writing, across all studies. Co-authors provided commentary.

I hereby declare that this thesis has not and will not be submitted in whole or in part to another University for the award of any other degree.

Signature:

Peter Hovard

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## University of Sussex

Peter Hovard

DPhil in Psychology

### **The role of cognitive, sensory and nutrient interactions in satiation and satiety: considering consumers**

### **Summary**

Previous research from the Sussex Ingestive Behaviour Group suggests that satiety beliefs generated by product information and satiety-relevant sensory characteristics (thick consistency and creamy flavours) can enhance the satiety response to covertly added energy in beverages. However these characteristics in low-energy beverages can generate rebound hunger effects. This thesis explored whether this enhanced-satiety concept can be translated to real consumers. Study 1 examined the extent of energy reduction that could be tolerated without rebound hunger effects. The original enhanced satiety concept was not replicated, although there was tentative evidence that energy compensation was more accurate for small energy additions. Study 2 explored whether enhanced satiety would prevail following repeated exposures in consumers' own homes. Enhanced satiety was found before and after exposure. Additionally focus groups suggested that diet-concerned consumers may be particularly interested in such products. Therefore in Study 3 this population, represented in the literature by those reporting high dietary restraint, was studied suggesting that those high in restraint and disinhibition compensated more accurately for energy in unenhanced beverages. A final complication for consumers is that believed healthy foods are often overconsumed. Two final studies demonstrated that health labels generated beliefs about the sensory experience and expected satiation and satiety of beverages. Tasting overrode the effects of these beliefs, although expectation-experience congruency led to assimilation of healthy beliefs, and indulgent-based fullness. Portion size selection was unaffected. Together the findings from these studies suggest that the enhanced satiety concept may have some utility in the real world, although it remains unclear as to how little caloric content can be tolerated whilst still enhancing satiety, and whether diet concerned consumers would benefit. Finally whilst health information may have a role in appetite expectations the interaction with sensory experience is important for generating overall product evaluations, and sensory experience is likely to override label information in dictating portion size selection.

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# 1 General Introduction

## 1.1 A multifaceted approach to appetite control

Contemporary approaches to appetite control consider a range of interacting influences, from the metabolic consequences of ingestion, to cognitive processes and sensory mechanisms. It has long been assumed that the primary driver of appetite and food intake is the homeostatic need to stabilise variables such as glucose, lipid, or amino acid availability, or body weight and temperature, as a requirement for life in a dynamic environment (Brobeck, 1948; Kennedy, 1953; Mayer, 1955; Mellinkoff, Frankland, Boyle, & Greipel, 1956; Nisbett, 1972). Animals are motivated to intake food during states of depletion and cease that motivation when replete, in the service of regulating such a parameter (see Berridge, 2004; Toates, 1981; Woods & Ramsay, 2007).

However, contemporary approaches to appetite acknowledge the role of cognitive and sensory aspects of appetite control that may operate independently of, and in interaction with, the metabolic consequences of ingestion. Some of these factors are reviewed in the course of this chapter, in particular the role of information that generates beliefs and expectations about the satiating capacity of foods.

The satiety cascade described by Blundell and colleagues (Blundell & Tremblay, 1995; Blundell, 1991, 2001; Blundell et al., 2010; Blundell, Gibbons, Caudwell, Finlayson, & Hopkins, 2015; Blundell, Hill, & Rogers, 1988) is a framework that describes how cognitive, sensory, post-ingestive and post-absorptive factors excite and inhibit appetite (Figure 1.1). The satiety cascade differentiates processes which bring about the cessation of feeding (satiation) from those which suppress further eating (satiety). Satiation is often measured by the caloric value of food consumed *ad libitum* on one particular occasion. Satiety is represented as the amount of an *ad libitum* test meal consumed following ingestion of a fixed portion (preload) of a test food (Blundell et al., 2010). Laboratory studies testing satiety often covertly measure the amount of food eaten following a preload using a concealed balance. The studies in this thesis used the Sussex Ingestion Pattern Monitor (SIPM; Yeomans, 2000), a universal eating monitor.

The SIPM integrates software which presents ratings and questions to participants and guides them through the experimental procedure, with a concealed balance beneath a placemat which records the weight of food every two seconds. This allows measurement of the final amount consumed (by subtracting final weight from starting weight of food). It also allows a feature used throughout this thesis whereby weight recording is paused and the participant instructed to call the experimenter for a refill when a certain amount of food has been consumed. In this way the participant can receive an unlimited amount of food, limiting the cues available to terminate eating other than as manipulated by the experimenter. A commonly used measure of satiety is energy compensation, which is calculated as the decrease in intake of a test meal relative to a control, expressed as a percentage of the difference in preload energy contents. The measure demonstrates the degree of response to ingestion of an energy load by decreasing the amount consumed at the next meal. Self-reported appetite ratings are also used to assess the intensity of appetite under different conditions before, during and after consumption of test foods. This thesis adopts these conceptualisations of satiation and satiety.

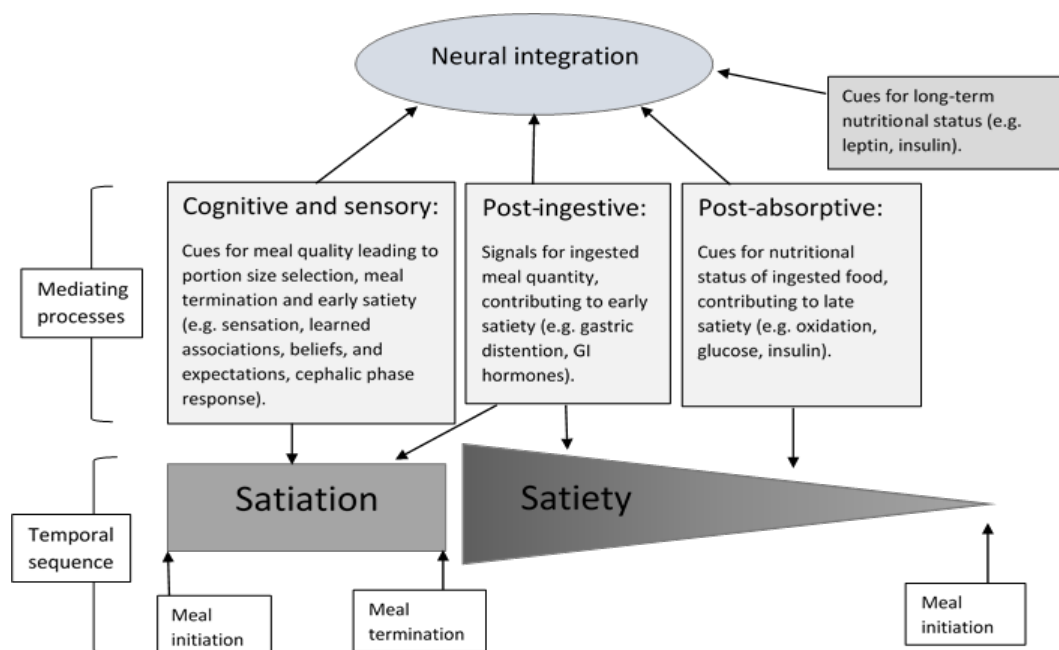
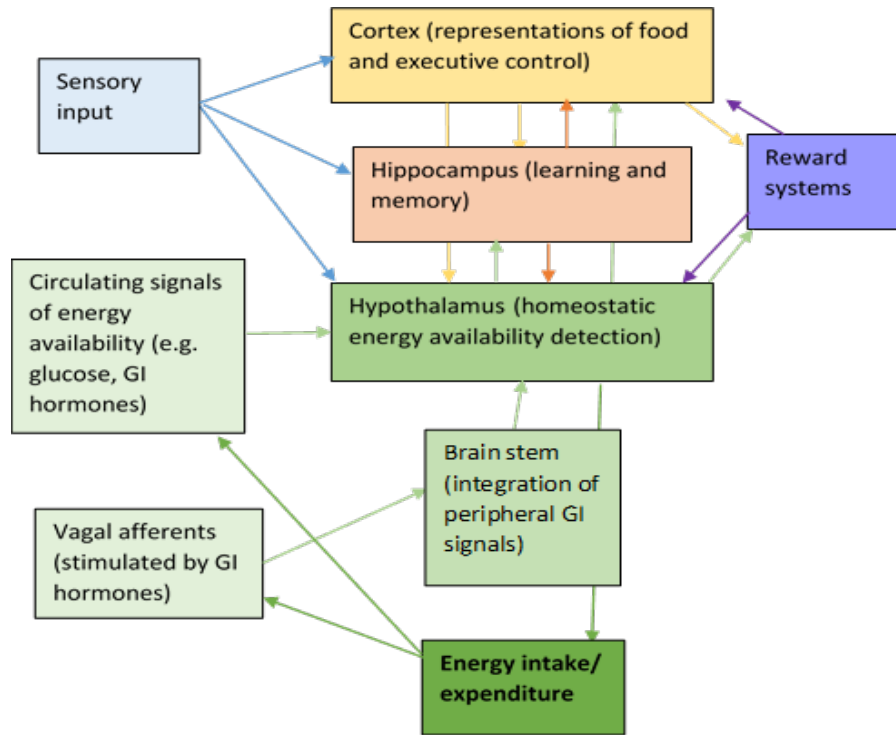


Figure 1.1 the satiety cascade diagram adapted from Blundell et al (2010).

The satiety cascade suggests that cognitive and sensory factors contribute to food choice, meal initiation, satiation, and the early stages of satiety; post-ingestive feedback contributes to satiation and satiety; and post-absorptive feedback contributes to the later stages of satiety. This view represents categories of signals about the state of the body and the nutritional consequences of ingestion, thus fulfilling homeostatic requirements, as well as using higher order beliefs and mental processes, learned consequences of ingestion, and sensory innervation of appetite control systems, to motivate and inhibit feeding behaviour. This paints a picture of an interacting system of signals (see Figure 1.1) that work together to influence decisions about what and how much to eat, and how the body responds to what has been eaten by suppressing subsequent feeding behaviour for a certain amount of time.

This view is supported by research into the neural representation of appetite control signals (e.g. Figure 1.2). Post-ingestive gastrointestinal (GI) signals converge and feedback to the brain via vagal afferents which project to the nucleus of the solitary tract (NTS) in the brainstem. The NTS projects to the hypothalamus which is also sensitive to circulating hormonal and nutritional (e.g. glucose) signals. These areas are typically associated with homeostatic control of energy demands (Berthoud, 2012) but are also linked to the reward circuitry (the prefrontal cortex, nucleus accumbens, ventral tegmental area and mesolimbic dopamine system), areas of the brain linked to executive control (the prefrontal cortex), representations of food stimuli (sensory cortex), and learning and memory (the hippocampus, e.g. Berthoud, 2004, 2012; Chambers & Sandoval, 2013; Myers & Olson, 2014; Zheng, Lenard, Shin, & Berthoud, 2009). Importantly this neural integration suggests a role for top down modulation of homeostatic metabolic signals by cognitive, sensory and reward regions, and conversely bottom up modulation of food representations and motivational properties by metabolic signals (Berthoud, 2012). For example, in their review Chambers and Sandoval (2013) report evidence that metabolic signals of nutritional state (e.g. leptin, a hormone produced in the adipose tissue as a signal of long-term energy stores) are linked to inhibition of dopaminergic neurons, suggesting that nutritional state can modify the

rewarding value of food. Overall homeostatic control of appetite is modulated by multiple cognitive, sensory and reward factors (Berthoud, 2012).



*Figure 1.2 a simplified (non-exhaustive) illustration of neural control of appetite. Particular focus on the interactions between homeostatic mechanisms (in green) and representations for food, including reward and learning. Adapted from Berthoud (2012).*

This integration illustrates the multifaceted nature of signals for appetite control and provides a rationale for a role of signals arising from multiple origins in determining satiation and satiety. Although not intended to be an exhaustive account, the following subsections highlight some of the signals involved, and how those signals interact. To begin, section 1.1.1 briefly describes the signals that arise in the GI tract as a result of ingestion, which inform the brain about the quantity and nutritional value of ingested food.

### 1.1.1 Peripheral post-ingestive and post-absorptive feedback

A key aspect of appetite control is the response of the body to a nutritional challenge (i.e. ingestion). Homeostatic control of food intake relies on negative feedback loops which inhibit appetite in response to the metabolic consequences of ingestion and the long term nutritional state of the body (e.g. Berridge, 2004). Ingesting food causes responses in peripheral physiological mechanisms which provide feedback to the brain via mechanoreceptor and chemoreceptor innervation of the vagus nerve, and through direct action of hormones in the circulation on the central nervous system (see Woods, 2004; Figure 1.2). Following is a brief overview of the role of gastric distention, hormonal signals of ingestion and long-term signals of energy stores. The work in this thesis does not directly impinge upon these mechanisms and therefore this account is not exhaustive (comprehensive reviews are available elsewhere e.g Kissileff & Van Itallie, 1982; Woods, 2004). Rather this is intended to demonstrate that the body is equipped to respond to nutritional delivery and modify appetite accordingly.

When food is consumed it arrives in the stomach resulting in gastric distention which stimulates mechanoreceptors innervating vagal afferents (Wang et al., 2008). Gastric balloon studies have demonstrated that gastric distention induced by inflation of a balloon in the stomach was related to the sensation of fullness (Oesch, Rüegg, Fischer, Degen, & Beglinger, 2006) and the degree of inflation was related to decreased simultaneous intake (Geliebter, Westreich, & Gage, 1988). Moreover the volume of food consumed is related to fullness independently of energy density (Rolls et al., 1998), suggesting that distention of the stomach is important for generating satiety (although volume effects could also be attributed to cognitions about the amount of food consumed, see section 1.1.2). This signal for satiety is mediated by the rate at which the stomach empties: a slow rate of emptying will lead to longer sensations of fullness caused by longer periods of gastric distention (Marciani et al., 2001). However, another gastric balloon study demonstrated that the qualitative sensations generated by distension by a gastric balloon were modified by specific nutritional infusion to the duodenum. Maltodextrin (a soluble carbohydrate) infusions generated sensations

reported to be more meal-like (Feinle, Grundy, & Read, 1997). Thus whilst gastric distention provides an important signal that food has entered the GI tract, the metabolic products of ingestants are likely to be important for generating appropriate appetite control signals.

Accordingly a cascade of hormonal signals provides feedback via chemoreceptors which innervate vagal afferents. These signals are relayed to the nucleus of the solitary tract where they are integrated and relayed to the hypothalamus. These signals also operate through direct action on the central nervous system (CNS) through the circulation (Woods, 2004). Hormonal signals arising from the gut include: cholecystikinin (CCK), glucagon-like peptide (GLP-1), polypeptide YY (PYY), pancreatic polypeptide (PP), gastrin releasing peptide, neuromedin B, enterostatin, somatostatin, apolipoprotein, amylin, glucagon, adiponectin and ghrelin (Woods, 2004). It is beyond the scope of this thesis to review these signals in detail, but several comprehensive reviews are available (e.g. de Graaf, Blom, Smeets, Stafleu, & Hendriks, 2004; Verdich et al., 2001; Woods, Decke, & Vasselli, 1974; Woods, 2004). As an example however, one much researched peptide hormone is CCK which is released in the duodenum in response to the presence of fat and protein and is thought to be related to the control of gastric emptying rate and therefore gastric distention during feeding, as well as intestinal motility and digestive enzyme secretion (Blundell, 2001; Chambers & Sandoval, 2013; Greenough, Cole, Lewis, Lockton, & Blundell, 1998). Endogenous CCK release, studied through CCK receptor antagonists (Dourish, Rycroft, & Iversen, 1989), and exogenous CCK infusion (Gibbs, Young, & Smith, 1973) has been linked to a dose dependent effect on hunger suppression and decreased food intake. Additionally infusions of CCK are associated with decreased pre-meal hunger ratings, increased fullness ratings and decreased intake that is unaffected by nausea and anxiety associated with the infusions (Greenough et al., 1998). Plasma levels of CCK are also correlated negatively with hunger and positively with fullness ratings, suggesting a post-absorptive role (French, Murray, Rumsey, Sepple, & Read, 1993).

These short-term signals are integrated in the brain with longer term signals of nutritional state relating to adiposity levels (Berthoud, 2012; Woods, 2004). For example, in the 1990s the protein leptin was discovered. Leptin is produced in the adipose tissue, acts peripherally and centrally and is correlated with adiposity (Blundell & Gillett, 2001; Margetic, Gazzola, Pegg, & Hill, 2002) suggesting it may act as a signal of energy stores. Whilst leptin infusion does not seem to influence appetite ratings related to short-term intake studies it has been shown to correlate with negatively with hunger ratings in 2-4 days food deprived participants (Mars, De Graaf, De Groot, Van Rossum, & Kok, 2006). It is likely that leptin is a signal for long-term energy stores.

The detection of these peripheral signals suggests that the GI tract (and adipose tissue), is equipped to feedback to the brain about the quantity of food ingested and the short and long-term nutritional state of the body. However, the ability to anticipate as well as react to the consequences of ingestion provides a survival advantage by removing the need to linger near food to determine whether it delivers satiety (Booth, Lee, & McAleavey, 1976), preparing the body for optimal digestion allowing greater quantities to be consumed (Power & Schulkin, 2008), and because integration of sensory and cognitive processes would facilitate adaptation to changing environments (Berthoud, 2012). The next sections overview some of the research which highlights pre-ingestive sensory and cognitive signals that influence portion size selection, satiation and early satiety.

### 1.1.2 Cognitive and sensory influences on satiety

The satiety cascade (e.g. Blundell et al., 2010) suggests that cognitive and sensory processes contribute to satiation and satiety through their action prior to and during ingestion. These facets of appetite control are considered in the next sections of this chapter. Firstly, it is acknowledged that a number of studies have observed effects of processes that could reasonably be categorised as cognitive and sensory on satiation and satiety. For example recent reviews have explored the roles of attention (Robinson et

al., 2013), memory (Higgs, Robinson, & Lee, 2012) and social cognition (De Castro & Plunkett, 2002) as top down modulators of appetite control mechanisms. Additionally, the idea of sensory specific satiety (SSS) suggests that appetites are inhibited for specific flavours (indicated by decrease in pleasantness ratings for a specific flavour but not for untasted flavours), suggesting that sensory signals influence appetite independently of nutritional signalling (Rolls, Rolls, Rowe, & Sweeney, 1981). There has also been significant attention to the role of sensory properties in stimulating appetite (for example see Yeomans, Blundell, & Leshem, 2007, for a review of the role of palatability in appetite control). A full discussion of these valuable insights is largely beyond the scope of this thesis, although it is worth noting the breadth of evidence that has examined appetite control beyond metabolic consequences of ingestion *per se*. The work in this thesis focusses on pre-ingestive orosensory factors and beliefs which result in anticipation of an influx of nutrients into the body, as well as how expectations influence decisions about portion size selection (this aspect discussed in more detail in section 1.1.3). Additionally, as explored in greater detail throughout the next section the strict distinction between signals as cognitive or sensory is not always justified. Accordingly here I use the terminology “cognitive and sensory” to relate to pre-ingestive cues that lead to explicit or implicit expectations of satiation or satiety, and discuss the role of orosensory factors and beliefs under this umbrella. The first discussions relate to how expectations and beliefs from cognitive and sensory sources could influence satiety, beginning with a mechanism through which these pre-ingestive factors could operate.

#### 1.1.2.1 The role of cephalic phase responses

Cognitive and sensory signals could influence appetite control by acting on physiological mechanisms. Section 1.1.1 above demonstrates that the body is equipped to generate signals about its short-term and long-term nutritional state, contributing to a homeostatic control of appetite and food intake. This section explores evidence that physiological control of appetite also occurs in anticipation of ingestion. This class of peripheral feedback relies on learned associations between sensory stimulation and



post-ingestive consequences (as well as some automatic responses) in anticipation of ingestion.

Cephalic phase responses (CPRs) are learned and automatic physiological reactions to cues to ingestion that occur prior to, or at the beginning of, ingestion (de Graaf et al., 2004; de Graaf, 2011; Smeets, Erkner, & de Graaf, 2010). The term ‘cephalic’, meaning pertaining to the head, relates to the role of receptors in the brain which are activated by sensory stimulation, rather than through gastric, post-ingestive feedback. CPRs operate through the activation of sensory pathways involved in the sight, smell, taste and thought (perhaps by stimulating sensory pathways through activation of learned associations) of food, ultimately activating the vagus nerve. This results in salivary responses, gastric acid secretions, pancreatic enzymes, insulin, glucagon, leptin, pancreatic polypeptide, CCK, and ghrelin release (for comprehensive overviews see Power & Schulkin, 2008; Smeets et al., 2010). These anticipatory responses may be useful for enhancing the efficiency with which the digestive system processes nutritional loads, minimizing the disruption caused to homeostatic states and optimizing digestive and absorptive processes (Woods, 1991; Woods & Ramsay, 2007). The CPR action of physiological signals for satiation and satiety suggests a mechanism through which pre-ingestive cues can influence appetite control. The next sections provide an overview of these factors.

#### 1.1.2.2 Orosensory influences on satiety

The influence of orosensory stimulation on appetite control has been explored in detail, with findings suggesting that sensory feedback is important for modulating the satiating effects of nutritional loads. Evidence for this assertion comes from studies in which orosensory stimulation is bypassed through direct infusion of nutrients at various stages of the GI tract. Findings from such studies suggest that the combination of orosensory, gastric and intestinal feedback generates greater satiety (Cecil, Francis, & Read, 1998, 1999; French & Cecil, 2001). Pertinently, sensory feedback is an influential component in generating satiety.

When energy is consumed in food contexts that do not promote adequate sensory feedback satiation and satiety may be weakened. Specifically, there is now substantial evidence that food form and texture influence satiation and satiety. One key finding is that energy consumed as a beverage is less satiating than an equal energy-load consumed as a solid meal. For example apples generate greater satiety than apple juice or puree as measured by subsequent intake and subjective fullness (Flood-Obbagy & Rolls, 2009). In one study self-reported dietary intake whilst using a supplementary liquid load was higher than when the supplement was a solid – participants compensated accurately for the increase in the energy in their diet when provided as a solid, but compensated poorly when the extra energy was in liquid form (DiMeglio & Mattes, 2000). Similarly Hulshof, De Graaf, & Weststrate (1993) demonstrated that solid preloads (as manipulated by additions of locust bean gum and gelatine to the liquid version) generated higher subsequent satiety ratings than liquid versions. This effect has been demonstrated in liquid and solid forms of high fat, protein and carbohydrate test foods (Mattes, 2005; Mourao, Bressan, Campbell, & Mattes, 2007), and alcoholic and non-alcoholic preloads (Mattes, 1996). Other studies have demonstrated that *ad libitum* intake of liquid products was greater than a semi-solid equivalent both before and after repeated-exposures, and reported satiety was lower for the liquid product (Hogenkamp et al., 2012).

Relatedly, textural characteristics influence the extent to which liquids are satiating. Increasing evidence now suggests that viscosity and creamy flavours predict expected and actual satiating capacity (Hogenkamp, Mars, Stafleu, & de Graaf, 2012; McCrickerd, Chambers, Brunstrom, & Yeomans, 2012). McCrickerd and colleagues (2012) showed that additions of tara gum, a soluble viscous fibre, increased the viscosity of beverages, as tested by rheological measurements. Viscosity was highly correlated with participants' ratings of textural characteristics, including thickness. This demonstrates that consumers can identify subtle differences in viscosity and represent this using thickness ratings. A number of studies have explored the relationship between perceptions of such textural characteristics and satiety. For example one study has suggested that whilst protein is considered to be the most satiating macronutrient these

effects may depend on the thick and creamy sensory properties of protein-rich beverages such that when controlling for these characteristics a protein beverage was no more satiating than and equicaloric carbohydrate based beverage (Bertenshaw, Lluch, & Yeomans, 2013). Similarly the viscosity of a beverage was negatively related to subsequent hunger in another study (Mattes & Rothacker, 2001). This finding has been supported by Zijlstra and colleagues who found that intake of a liquid was greater than a semi-liquid, which in turn was greater than a semi-solid, suggesting that increased solidity increases satiation (Zijlstra, Mars, de Wijk, Westerterp-Plantenga, & de Graaf, 2008). Additionally this study tested participants in a ‘real-life’ setting, a cinema, in an attempt to explore these orosensory effects outside of the laboratory. In a test of the influence of food form on subjective and physiological appetite markers, subjective ratings of satiety were higher following a semi-solid than a liquid product, although no effect of hormonal changes was observed, other than an unexpected increase in ghrelin levels following the semi-solid (Zijlstra, Mars, et al., 2009). Whilst not all studies have demonstrated a reduced satiating effect of liquids (Almiron-Roig, Flores, & Drewnowski, 2004; Drewnowski, Flores, & Almiron-Roig, 2004), recent systematic reviews have found that compensation for energy additions to preloads was weaker when consumed in liquid form, if consumed at volumes of less than 600ml and with inter-meal intervals of over 30 minutes (Almiron-Roig et al., 2013; Almiron-Roig, Chen, & Drewnowski, 2003).

One key theory is that liquids, particularly low viscous ones, are related to shorter oral-exposure time which may be associated with lesser satiety-related sensory feedback (Hogenkamp & Schiöth, 2013). Liquids are considered to be “fast foods” in the sense that they require less oral transit time (de Graaf, 2011). In studies which have manipulated eating rate, and thus oral exposure time (Forde, van Kuijk, Thaler, de Graaf, & Martin, 2013), through varying consumption with either a straw or spoon, *ad libitum* intake was greater in the shorter exposure (straw) condition (Hogenkamp, Mars, Stafleu, & Graaf, 2010). Other studies have demonstrated that increasing the number of chews or eating rate, thus influencing oral processing time, decreased satiation with decreased oral exposure time (Smit, Kemsley, Tapp, & Henry, 2011) and also increased

GLP 1 levels with increased exposure time (Cassady, Hollis, Fulford, Considine, & Mattes, 2009; Li et al., 2011). Oral processing time has also been shown to correlate positively with expected satiation, suggesting an anticipatory component (Forde et al., 2013). These findings could be explained through the increased influence of CPRs given increased pre-ingestive feedback (de Graaf, 2011). Additionally this reduced orosensory feedback may be related to reduced efficacy in nutritional learning. A study by Mars, Hogenkamp, Gosses, Stafleu, and De Graaf, (2009) demonstrated that over repeated exposures energy intake of a high energy yoghurt was only reduced in a high-viscosity condition, suggesting that nutritional learning only took place when orosensory feedback was sufficient. In addition to oral transit time, food representations stimulated by sensory characteristics may be related CPRs via learning. In relation to food texture it is likely that viscosity is a good predictor of energy delivery. Studies have demonstrated that breast milk viscosity is positively correlated with nutritional content (McDaniel, Barker, & Lederer, 1989; Picciano, 1998). Thus humans may learn from an early age that viscosity is related to energy delivery. Indeed it has been suggested that there is a critical period for dietary learning in humans (Brunstrom, 2005), in which case it is likely that human infants learn early that viscous liquids are likely to deliver satiety. It is likely also that humans have a lifetime of learning a relationship between viscous foods and satiating consequences. Viscous foods often are more nutrient-rich than fluids or low viscous foods (Chambers, 2015, Davidson & Swithers, 2005) making texture a reliable cue for nutritional content (Davidson & Swithers, 2005). Therefore early experiences and continual associations align viscosity with satiating consequences. It is plausible then that encounter with viscous liquids could lead to learned preparatory changes in physiology to prepare for nutritional delivery. According to these perspectives sensory cues from foods may be related to anticipating satiating consequences, and influencing actual satiety, through modulating feedback.

### 1.1.2.3 The influence of beliefs from product framing and context on satiety

The discussion of orosensory factors above suggests that nutritional loads are anticipated by association with sensory properties, generating sensory feedback that influences appetite control mechanisms. Similarly, consumers' beliefs about foods may influence anticipation and growing evidence suggests that this influences satiety. These beliefs derive from explicit information relating to the energy or nutritional content of a particular food through product labelling or framing. For example, an interesting study has demonstrated the influence of beliefs generated from product information on appetite. The study investigated the hormonal response to consuming products presented as "low-calorie" and "sensible", or "high-calorie" and "indulgent", finding that the indulgent labelled beverage suppressed ghrelin response following consumption whereas the sensible product generated little change in ghrelin response, despite participants having consumed an identical beverage (Crum, Corbin, Brownell, & Salovey, 2011). Crum and colleagues' study provided interesting insights into how product framing can modulate the response of peripheral appetite controls. However the study did not provide a neutral message control group making it difficult to determine whether the effect could be attributed to high-calorie, satiety-relevant, or low calorie, hunger-relevant, expectations. Additionally, whilst the information presented to participants in this study may have generated specific nutritionally relevant beliefs the terminology used to manipulate those beliefs could reasonably relate to sensory expectations. In particular the term "indulgent" conjures thoughts of a product with a particular sensory profile (perhaps sweet and creamy characteristics). It is conjecture then, but plausible, that these findings also relate to sensory effects.

Consumer beliefs that influence appetite control may also be derived from less overt references to caloric content. Foods which are considered more substantial or more like a food than a beverage may be associated with higher satiety. An early study demonstrated that presenting a beverage as a high calorie product suppressed subsequent appetite and intake of a test meal to a greater extent than when the beverage was presented as a diet product (Wooley, 1972). The manipulation in this study

influenced consumer beliefs by altering the sensory properties of the preload as well as label information. The believed high calorie preload was designed to resemble an indulgent milkshake whereas the believed low calorie version had a thinner consistency. Whilst the authors attribute the findings to a cognitive effect it is unclear whether specifically sensory processes, such as increased oral exposure time of the believed high calorie preload, could account for the findings. Similarly another study demonstrated that despite their liquid form, which, as described above, is thought to be related to lower satiety, soups deliver relatively high satiety (Mattes, 2005). The author attributes this effect to cognitive factors involved in eating a soup, such as the use of a spoon, which frames it as an activity for suppressing hunger rather than thirst. Again the use of a spoon to consume a soup would also be likely to increase oral exposure time (Hogenkamp et al., 2010), thus making it difficult to separate cognitive and sensory effects. Relatedly, a recent study (Cassady, Considine, & Mattes, 2012) manipulated consumers' beliefs such actual liquids and solid were shown to participants to become liquids or solids once consumed, thus creating an actual and believed liquid group, an actual and believed solid group, a liquid believed turning to solid group and a solid believed turning to liquid group. Both the actual and believed liquid groups reported greater subsequent hunger and lower fullness, faster gastric emptying rate, suppressed insulin and GLP-1 release (see section 1.1.1) and lesser suppression of ghrelin release, than the believed solid groups. Additionally, believed liquid consumption was associated with greater subsequent intake. This study demonstrates that consumers' beliefs about a food can influence subjective appetite, intake and physiological response to ingestion, although again the expectations generated ultimately related to sensory aspects (the stimuli generated expectations about food form). Two other studies have demonstrated satiety effects purely by altering the context in which a food is consumed. One study manipulated the belief that a food was either a meal or a snack by arranging an ordinary meal context (eating with a knife and fork at a table). When the food was presented as a meal participants ate less subsequently (Pliner & Zec, 2007). Meanwhile Capaldi, Owens, & Privitera (2006) demonstrated that presenting a preload as a snack also led to increased subsequent intake. It is plausible again that this framing relates to the activation of sensory feedback mechanisms. It may be that a "snack" conjures

beliefs about a smaller amount of food than a meal, and therefore less gastric distention. These studies demonstrate that beliefs about foods generated by the way in which they are framed can influence satiety responses, although it is unclear whether this ultimately relates to sensory representations. This is plausible given that retrieval of knowledge activates cortical areas involved in sensory processing (Goldberg, 2006), and thus could activate CPRs in the absence of actual sensory stimulation (Smeets et al., 2010). Nonetheless the above suggests that satiety relevant beliefs (whether through sensory mechanisms or otherwise) can contribute to actual satiety, modulating the peripheral appetite control mechanisms involved. This demonstrates the links between sensory and cognitive processes (and the awkward terminology which separates them) and the integration of multiple levels of feedback in satiety.

The majority of the above studies investigated beliefs by manipulating the context in which foods are consumed. However a few gave explicit information through labelling (Crum et al., 2011; Wooley, 1972). Other studies have investigated the role of labelling in satiety, finding no effects of labels above actual nutritional content or orosensory effects (Chambers, Ells, & Yeomans, 2013; Yeomans, Lartamo, Procter, Lee, & Gray, 2001). One reason could be that people fail to believe the authenticity of labels presented in laboratory contexts thus reducing their effects. Another possibility is that label effects can be overridden in situations where nutritional or sensory cues are strong. This is supported by a recent study which demonstrated a greater effect of sensory cues than providing information about the satiating potential of a beverage (McCrickerd, Chambers, & Yeomans, 2014b).

Overall the research discussed in this section suggests that the sensory context and beliefs related to consuming nutritional loads can modulate the behavioural, subjective and physiological satiety response. Following is an overview of research which has explored the specific interactions between cognitive, sensory and nutritional components of satiety.

#### 1.1.2.4 The cognitive-sensory enhancement of satiety

The above sections argue that intake and appetite control are governed by a combination of post-ingestive feedback, and feedback from sensory stimulation and beliefs about foods. However one key challenge for researchers adopting this integrated approach is to explore the specific ways in which the different signals interact.

A series of studies by Yeomans' laboratory has looked into interactive effects between cognitive, sensory and nutritional factors on satiation and satiety. These studies tested the idea that providing sensory cues that might predict the presence of energy would enhance the satiety response to covert energy loads in the context of smoothie-like beverages. Creamy flavour notes and particularly viscosity were found to be related to expected satiety in this context (McCrickerd et al., 2012), suggesting that these properties could be used to anticipate satiety. Similarly in another study reducing emulsion oil droplet size increased perceptions of creaminess and this was related to increased palatability and increased expected satiety (Lett, Yeomans, Norton, & Norton, 2016). Importantly, thickening beverage preloads with tara gum, a viscous fibre, and enhancing creamy flavours has been robustly demonstrated to enhance actual satiety relative to beverages devoid of these characteristics, but only when sufficient energy was delivered (Chambers, Ells, & Yeomans, 2013; McCrickerd, Chambers, & Yeomans, 2014; Yeomans & Chambers, 2011; Yeomans, McCrickerd, Brunstrom, & Chambers, 2014). In the first of these studies covert additions of 200kcal of maltodextrin (a soluble carbohydrate) and whey protein was compensated for more accurately in sensory-enhanced contexts. Conversely the presence of these characteristics in low-energy beverages led to increased hunger (Yeomans & Chambers, 2011). The authors explain these findings in that the satiety-relevant sensory characteristics led to anticipation of nutritional delivery due to increasing cognitive and sensory feedback. When delivered the nutritional load is noticed and feedback is efficient, leading to enhanced satiety, whilst anticipation of energy which does not arrive leads to activation of preparatory responses that are not satisfied, leading to hunger (Chambers, McCrickerd, & Yeomans, 2015).



A follow-up study assessed the effects of repeated exposure to the sensory-enhanced beverages (Yeomans et al., 2014). Sensory enhanced and non-enhanced versions of high and low-energy beverages were consumed seven times in total, with satiety testing occurring after the first and sixth exposure, and one month later. The findings suggested that compensation for the covertly added energy was enhanced by sensory cues at the first exposure, however the sensory cues did not influence satiety following the exposure period. These findings suggest that participants were able to learn about the energy content of the beverages and adjust their intake accordingly after repeated exposure, thus diminishing the influence of sensory cues. These ideas have also received support from other laboratory groups. A similar study demonstrated that satiety predictive sensory properties (viscosity) generated reduced intake of high energy beverage whereas following repeated exposure only the energy content influenced satiety (Hogenkamp, 2014).

Similarly, recent research has investigated the integration of contextual cues with sensory cues and post-ingestive cues in determining satiety. In one study high and low-energy versions of a beverage were presented as either thirst quenching, filling or no information and were compared to a sensory-enhanced product. Compensation for the extra energy in the high energy products was improved by presenting it as filling relative to thirst quenching or no information (McCrickerd et al., 2014b). However the sensory enhanced condition in this study generated the greatest compensation suggesting that sensory cues are more potent in generating enhanced satiety than are beliefs generated by information prior to ingestion. This idea is supported by an earlier study which found that whilst sensory cues generated enhanced compensation, additional information provided by labels which presented the beverage as filling or light found no additional influence (Chambers et al., 2013). Similarly, in another study framing a product as high-energy (by stating the caloric content) did not enhance the satiating capacity of a high-energy version (Hogenkamp et al., 2013). However this may be because the preload used contained a far greater energy density (530kcal/300g) than Yeomans' laboratory's studies (270kcal/300g), suggesting ceiling effects based on the consumption of large amounts of energy. These studies suggest that there may be

something of a hierarchy in the influence of predictive cues to satiety: orosensory cues may override information from labels or explicit beliefs about foods, but in cases of large energy loads predictive cues may be ineffective at generating greater satiety. It is also worth noting that the results of McCrickerd et al.'s (2014) study were influenced by greater intake following the enhanced sensory low energy preload, thus increasing compensation scores (given that compensation is calculated as the relative difference in intake following low and high-energy preloads). This increased intake supports the idea of “rebound” effects (Yeomans & Chambers, 2011), as described above, whereby anticipation of energy delivery is not met. However, whilst this is a plausible explanation, increases in intake in these low-energy conditions that are essentially used as control conditions influence compensation scores. Further work is therefore needed to establish the degree to which sensory effects override cognitive influences on appetite control and whether rebound effects exaggerate differences in enhanced low-energy conditions.

Finally a related experiment tested the idea that the umami taste predicts the presence of protein, and can influence protein rich foods' satiating power. The study demonstrated that additions of monosodium glutamate which generated umami tastes enhanced compensation for protein rich soups (Masic & Yeomans, 2014). This again suggests that sensory properties can influence the satiety response to hidden nutritional loads by providing predictive cues. In this case the effect seemed to be macronutrient specific (umami flavours predicted protein delivery). However the previous studies used viscosity and creamy flavours as cues, finding effects in mixed carbohydrate and protein based preloads (Chambers et al., 2013; Yeomans & Chambers, 2011) as well as high-carbohydrate based preloads (McCrickerd, Chambers, & Yeomans, 2014a; Yeomans et al., 2014). Therefore the macronutrient specificity of predictive cue effects on satiety remains unclear.

In general, the above described studies demonstrated that cues improve satiety responses to energy-containing beverages. However when the cues are present in low-energy beverages rebound hunger can occur. One question which arises from this is to

what extent can energy be reduced from sensory-enhanced beverages whilst maintaining enhanced satiety effects? This is particularly important given that a systematic review of factors which influence compensation demonstrated that lower energy preloads were related to more accurate compensation. However this was only the case in semi-solid and solid preloads, whilst liquid preloads generated poor compensation in most contexts (Almiron-Roig et al., 2013). As such it is unclear as to whether providing sensory cues in liquid preloads would generate greater compensation for small covert energy additions. This question is important to consider if satiety benefits can be transferred to real consumers. Presently a common design strategy for diet products is to minimise caloric content whilst attempting to match the sensory profile of palatable high-energy products (Yeomans, 2015). According to the sensory-nutrient interaction research this is clearly counterproductive. However it is plausible, but unknown, whether small energy additions in products with sensory cues would be compensated for. Other possibilities for exploring how the enhanced-satiety concept can be translated to consumers are reviewed in section 1.2.

### 1.1.3 Expectations and satiation

The discussions of sensory influences and beliefs so far have demonstrated that expectations about the satiating potential of foods can influence the physiological response to ingestion and the behavioural satiety response. The discussion now turns to the control of meal size within one eating occasion – satiation. There may be situations in which post-ingestive feedback is insufficient to terminate eating (for example due to the rate of eating) at an appropriate level (Brunstrom, 2005; Illius & Jessop, 1995), and it is not necessarily the case that people consume and stop consuming in response to internal appetite cues in all contexts (Blundell et al., 2010). Therefore external cues are recruited to influence the termination of eating. The following sections consider the role of expected satiation and satiety, and the implications of expectation-experience mismatches. Firstly however, one particular case in which expectations may influence satiation, with real consumer-relevance, is considered: the role of health beliefs.

### 1.1.3.1 The case of health halos

The work in this thesis is concerned with how an integrated approach to appetite control, involving the influence of expectations, can benefit consumers. The case of health halos highlights a potential problem that consumers face due to the effects of these expectations. It is broadly communicated that the developed world faces an obesity crisis and that obesity has severe health consequences (Mozaffarian et al., 2015). Consequently there is significant public attention to dietary healthfulness, for example the well-known United Kingdom public health campaign ‘Five a Day’ which encourages the consumption of five portions of fruit and vegetables per day (Ashfield-Watt, Welch, Day, & Bingham, 2004). Additionally marketers have used this opportunity to promote the health-benefits of their products, and studies support the idea that promoting health-relevant properties of foods facilitates choice for those foods (Grabenhorst, Schulte, Maderwald, & Brand, 2013; Kozup, Creyer, & Burton, 2003). However it is possible, bearing in mind the role of expectations in appetite control, that these health beliefs could influence appetite and intake.

Halo effects in socio-cognitive psychology refer to the idea that favourable information concerning a stimulus may be overgeneralised to the whole stimulus leading to overall enhanced favourable impressions not grounded in the actual available evidence. Additionally, favourable beliefs are related to the attribution of additional favourable characteristics to the stimulus in the absence of explicit substantiating information (Nisbett & Wilson, 1977). Therefore in the food context believed healthy foods could promote over-generalised beliefs. For example consumers interpret low fat claims as low calorie (Andrews, Netemeyer, & Burton, 1998). This is supported by findings that in believed healthy foods caloric content is underestimated (Carels, Harper, & Konrad, 2006), appropriate serving size and intake norms are increased (Chandon & Wansink, 2007), and guilt associated with eating actual caloric foods is reduced (Brian Wansink & Chandon, 2006). Additionally in one study it was found that health labels on supermarket products led to more positive summaries of the product, higher evaluations of unmentioned positive characteristics, and attribution of unmentioned health benefits

to the product (Roe, Levy, & Derby, 1999). Similarly, in another study health labelling led to holistic, stereotyped judgements and binary good or bad evaluations (Oakes & Slotterback, 2001; Oakes, 2005). Thus health labels may be involved in promoting holistic judgements about products which over-emphasise their healthfulness and attribute unwarranted positive characteristics.

Related research on the influence of value based claims has demonstrated similar halo effects. For example over two studies Schuldt, Muller and Schwarz (2012) presented dark chocolate with fair trade labels, and even merely a description that the chocolate was produced ethically (i.e. without reference to the recognised Fair Trade brand). Despite no reference to caloric content in these labels the fair trade and ethically produced chocolate was estimated to have lower caloric content. Similarly other studies have demonstrated that labelling products as organic lead to lower calorie estimations, higher estimations of acceptable consumption frequency, and higher acceptability of missing exercise (Lee, Shimizu, Kniffin, & Wansink, 2013; Schuldt & Schwarz, 2010). The findings of these studies are particularly striking given that the fair trade and organic labelling has little logical resemblance to caloric content. The authors attribute the effects to the use of heuristic processing, a phenomenon described by dual process theories of cognition, whereby certain contexts lead to rapid associative processing of stimuli using rules of thumb (e.g. Kahneman, 2003). This can lead to small errors, as in the case of believing healthy, fair trade or organic products to be less caloric despite inadequate information to support this belief. This is supported by the additional finding from Lee and colleagues (2013) that the effects of the organic label were more pronounced in those who do not ordinarily appraise food labels or engage in pro-environmental activities. This is purportedly because automatic, heuristic processing was more likely in those who did not interrogate the labels thoroughly.

Additionally food descriptions, including health-related descriptions, likely influence sensory evaluations of foods (Brian Wansink, Payne, & North, 2007; Brian Wansink, van Ittersum, & Painter, 2005). For example reduced salt labels on soups lead consumers to report lower saltiness and add more salt to the soup compared to soups

without the label, even though salt content was not actually reduced (Liem, Miremedi, Zandstra, & Keast, 2012). Similarly eco-friendly labels have been found to increase palatability ratings for bananas, grapes and raisins (Sörqvist et al., 2015), coffee and chocolate (Lotz, Christandl, & Fetchenhauer, 2013), and organic labels increase palatability ratings of wine (Wiedmann, Hennigs, Henrik Behrens, & Klarmann, 2014).

These studies offer interesting insight into biases in the evaluation of foods and food choices, but fewer studies have investigated the extent to which this influences actual intake or satiety responses. Given the findings discussed in section 1.1.2 that contextual factors and information generating beliefs about foods can influence the amount of food people serve themselves, the amount they consume and the satiety that the food delivers, it is plausible that health labelling and the over-generalised beliefs that it promotes could influence appetite control and intake. Indeed, Provencher, Polivy, & Herman (2009) found that participants consumed 35% more of an *ad libitum* cookie meal when the cookies were described as healthy than unhealthy. In this particular case no non-label control group was assessed making it difficult to determine whether these effects were due to over-eating of the believed-healthy cookies or whether the unhealthy information provided generated satiety cues. Another study has demonstrated that overweight consumers overate snack foods described as low-fat relative to those omitting health information (Brian Wansink & Chandon, 2006). Furthermore fast food restaurants who market themselves as healthy may promote underestimation of the caloric content of their meals, and are associated with higher calorie side dish orders (Chandon & Wansink, 2007). However this study interpreted healthiness from the researchers' interpretation of the restaurants' marketing strategies, rather than the consumers' beliefs (consumers were recruited on leaving the restaurants and the caloric value of the foods they had purchased was calculated). Therefore it is unclear as to whether healthiness beliefs *per se* contributed to the purchase decisions. A final study demonstrated the influence of healthy-framing on satiety. In this study participants consumed a 50kcal snack bar described as a new healthy option filled with "protein, vitamins and fibre", a "tasty" chocolate option or consumed nothing. The results suggested that participants reported higher levels of hunger following consumption of

the healthy snack than either the no snack or indulgent snack conditions (Finkelstein & Fishbach, 2010a). However the use of a no snack control group in this study makes it difficult to assess the independent impact of the label and of the energy load. Specifically in this case, and with reference to the rebound hunger effects described in section 1.1.2.4, the intended healthy description included the addition of protein and fibre, both known to be highly satiating (e.g. Blundell, Green, & Burley, 1994). However the snack only delivered 50kcal. It is possible that this effect reflects a rebound hunger effect, rather than a health-halo effect. A further limitation of all of the above studies is that they fail to consider the role of sensory characteristics in generating health beliefs, focussing instead on explicit information. However as discussed earlier, a number of studies have noted a greater role for sensory characteristics in influencing appetite and intake (Chambers et al., 2013; McCrickerd et al., 2014b). Expectation matching between health information and product experience is also a potential factor (see section 1.1.3.3). The above studies do not take into account situations in which health information is provided about products, but the sensory experience of those products disconfirms the expectations. The outcome of this expectation matching is likely to influence the degree to which a halo effect is observed (as discussed in greater detail in the following sections).

Overall the health halo research suggests that consumers face a problem related to the health benefits promoted by marketers in the wake of food-related public health concerns such as obesity. However the above analysis suggests a number of issues with the current research. Namely that control groups are often inadequate for determining whether intake effects can be attributed to health halo type effects, or satiety cues. Additionally it is currently unclear as to whether expectation matching effects might influence intake and product evaluations in health halo type studies.

#### 1.1.3.2 Explicit satiation and satiety expectations – an influence on satiation?

An additional possible influence of expectations comes from findings that people hold explicit expectations about the satiation and satiety that foods will deliver, and these

expectations can influence portion size selection (Brunstrom, Collingwood, & Rogers, 2010; Brunstrom, 2014; Fay et al., 2011). Given that intake is strongly influenced by portion size, regardless of energy density, and even if the entire portion is not consumed (Rolls, Morris, & Roe, 2002; Rolls, Roe, & Meengs, 2006; Brian Wansink & Cheney, 2005; Brian Wansink, Painter, & North, 2005; Brian Wansink & van Ittersum, 2007), factors which influence portion size selection are likely to influence intake. Some researchers have examined the relative expected satiation and satiety delivered by foods using pictorial stimuli. For example Brunstrom and colleagues have used a method of constant stimuli whereby a pictured target food is compared to a succession of comparison foods which vary in energy content. Participants are required to report which of the foods would be more satiating such that over repeated trials a point of equality between the foods is established and the relative caloric content of equally satiating meals can be compared (Brunstrom, Shakeshaft, & Scott-Samuel, 2008). Additionally, in a modified version of the task known as the method of adjustment, participants can gradually alter the depicted portion size of a range of reference foods until it represents an expected equally satiating portion to the target food (Brunstrom, Collingwood, et al., 2010).

Findings from these studies suggest that, calorie for calorie, foods are not necessarily expected to be equally as satiating (Brunstrom et al., 2008). Expected satiation is influenced by the familiarity of the foods, such that more familiar foods are expected to be more satiating (Brunstrom, Shakeshaft, & Alexander, 2010; Brunstrom et al., 2008; Irvine, Brunstrom, Gee, & Rogers, 2013), which suggests that learning about the actual satiating consequences of ingestion of particular foods influences expectations about that food. Additionally one study (Wilkinson & Brunstrom, 2009) demonstrated that exposure to a high energy novel desert increased expected satiation (measured using the method of adjustment). This suggests that expected satiation is based on previous post-ingestive consequences in familiar foods. This reflects the idea of learned satiation whereby the sensory properties of foods are associated with sensations that occur towards the end of a meal. In future the sensory properties of the food generate expectations about the amount needed to generate satiety (e.g. Booth & Davis, 1973;



Booth, Lee, & McAleavey, 1976; Booth, 2009). In unfamiliar foods expectations may be guided by physical characteristics such as volume (Brunstrom, Collingwood, et al., 2010), and weight (Piqueras-Fiszman & Spence, 2012). Another study demonstrated that satiety expectations were generated by beliefs about a presented food. Participants were shown a small or large portion of fruit purportedly to make a smoothie. The smaller portion was associated with lower expected satiety (as indicated by responses using the method of adjustment) and increased hunger ratings for three hours following consumption of a smoothie that was actually identical (Brunstrom, Brown, Hinton, Rogers, & Fay, 2011). These studies suggest that people hold expectations about the extent of satiation and satiety a food will deliver, and that this can influence the way they report their ideal portion size and subjective appetite.

Some studies have used an adapted version of the method of adjustment whereby participants consumed a sample of the test products with reference to a real version of the test product to control expected volume. These studies found that thick and creamy orosensory characteristics were related to higher expected satiety (Hogenkamp et al., 2012; Hogenkamp, Stafleu, Mars, Brunstrom, & de Graaf, 2011; McCrickerd et al., 2012; Yeomans et al., 2014). Other studies have used visual analog scales (VAS) to examine expectations in the context of actually consuming foods, demonstrating that expected satiation is related to sensory attributes such as ‘chewiness’ (Forde et al., 2013) and creaminess (Lett et al., 2016; McCrickerd, Lensing, & Yeomans, 2015). These adaptations of the expected satiation and satiety measurement procedure allow expectations to be measured based on the sensory profile of test foods, demonstrating that properties which generate sensory feedback are related to expected satiety.

The important element of explicit expectations for this thesis is the degree to which they contribute to appetite control and intake. Other studies using the method of adjustment have found that expected satiety is a better predictor than expected liking of portion size selection, measured by indicating an ideal portion size using computerised pictures of foods (Brunstrom, Collingwood, et al., 2010; Brunstrom & Rogers, 2009). One limitation of these studies is that they have not demonstrated the ability of expected

satiation and satiety to influence satiation *per se*. Although implied through the role of expectations on portion size selection, these results remain unclear. The studies described above (Brunstrom et al., 2011; Brunstrom, Collingwood, et al., 2010; Brunstrom & Rogers, 2009; Irvine et al., 2013) measured ideal portion size pictorially which fails to represent the rich sensory experience associated with real food cues. One study attempted to address this criticism, demonstrating that expected satiety measured using the method of adjustment predicted actual portion size selection of a real food (Wilkinson et al., 2012). However expectations were rated using computerised pictures, thus limiting the sensory experience of the comparison foods. Additionally the prior ratings of ideal portion size may have influenced actual portion size by priming representations of appropriate portion size. Overall there are limitations with the method of constant stimuli and method of adjustment in measuring portion size selection, and moreover these studies fail to measure whether initial portion selection accounts for the amount consumed *ad libitum*. Thus the exact role of expected satiation and satiety in satiation *per se* remains largely unclear.

#### 1.1.3.3 A role for explicit expectation matching

An additional factor which is overlooked by this approach is the effect of matching expectations with experience. The studies described above demonstrate that both external information (e.g. physical characteristics) and sensory characteristics can contribute to expected satiation and satiety. However the extent to which these influences interact is unclear from this literature. Expectation matching has been studied widely in the literature on food acceptance and hedonics (see Cardello, 1994; Deliza & MacFie, 1996). The assimilation-contrast model (Hovland, Harvey, & Sherif, 1957) predicts two types of outcomes: assimilation effects are indicated by enhanced ratings in the same direction as initial expectations, and occur when expectations and experience are congruent; contrast effects are indicated by a change in ratings away from the initial expectation and occur when expectations and experience are incongruent. This implicates the degree of disconfirmation of prior expectations whereby small and unnoticed discrepancies might lead to assimilation whereas larger, noticeable

discrepancies lead to contrast. This idea has also been related to more modern dual process theories of cognition (e.g. Evans, 2008; Kahneman, 2003). The strength and accessibility of expectations determine the depth of cognitive processing and therefore the likelihood of assimilation and contrast effects. In cases where there is no expectation, or weak expectation, participants process the stimulus in great detail in order to form an opinion. When there is a strong expectation however, and initial evaluation of the stimulus is consistent with the expectation, little processing is required to generate overall evaluations. These cases lead to assimilation of evaluations with expectations. On the other hand, when expectations and experience are incongruent, and the discrepancy is noticed, effortful processing must occur in order to evaluate the stimulus as confirmatory biases cannot be engaged to resolve the discrepancy. In this case contrast effects are most likely to occur given that the stimulus is evaluated in great detail. In this context the likelihood of rapid or effortful processing is predicted by certain aspects of a stimulus evaluation context that influence the likelihood of effortful processing, such as the degree of discrepancy between expectations and stimulus quality, the ambiguity of the stimulus, and the strength of prior expectations (Wilson & Klaaren, 1992).

These expectation congruency effects have been explored in the ingestive behaviour domain in relation to food acceptability. Cardello and Sawyer (1992) demonstrated that a neutrally liked commercial juice (represented by a mean acceptability score of 5 on a 9 point scale) was considered more acceptable when positive expectations were generated (by written information that other consumers had found it to be highly likable product) than no expectations. This supported an assimilation effect. Meanwhile in the same experiment a neutrally bitter solution was rated as less bitter than control when expected to be highly bitter, demonstrating a contrast effect. Assimilation of hedonic and sensory expectations has been described in a number of studies employing various ways of generating expectations, such as dining context, food preparation methods and label information (e.g. Cardello, 2003; Di Monaco, Cavella, Di Marzo, & Masi, 2004; Kähkönen & Tuorila, 1998; Liem et al., 2012; Tuorila, Cardello, & Leshner, 1994). It seems that congruency between expectations and experience (or small incongruences)

are likely to generate assimilation effects. Some authors have noted that even experiments in which expectations were disconfirmed contrast effects are rare (Cardello, 1994). However in another study participants were provided with a smoked salmon ice cream described either as a savoury mousse or as ice-cream. The findings suggested that hedonic evaluation was diminished to a greater extent when participants expected to experience ice cream, and other sensory ratings such as saltiness were also altered (Yeomans, Chambers, Blumenthal, & Blake, 2008). Similarly, Zellner, Strickhouser, and Tornow (2004) demonstrated that hedonic contrast effects were dependent upon the degree of certainty participants had in their expectations. The results suggested that participants disliked the taste of an unfamiliar Japanese sweet more when it was presented as a “candy” than a “mouth cleanser” or with no information, suggesting a contrast effect. However, when a separate group of participants were told that the sweet was rated by other Americans as positive or negative, thus generating more certain expectations, assimilation was observed. These findings support the idea that large, noticeable expectation-experience mismatches generated contrast, but smaller mismatches or congruencies promoted assimilation of expectations.

Whilst these studies demonstrate clear effects of mismatching between expectations and experience they all relate to hedonic and sensory evaluations of products. Meanwhile the above suggests that the degree to which people expect satiation and satiety, or healthiness, from a product can influence portion size selection. However this literature has not examined the circumstances in which those expectations are confirmed or disconfirmed, and what effects that has on portion size selection.

## 1.2 Misrepresenting real consumers

In summary, the above discussions suggest that the interaction between energy content and satiety-relevant cues determines satiety and satiation. Sensory cues are able to enhance the satiety response to covertly added energy loads, although, when these cues are present in low energy beverages increased hunger ratings are reported. However, it

is unclear as to the extent of nutritional delivery that is required to generate efficient energy compensation without risking rebound hunger effects in sensory-enhanced beverages. This is clearly an important question to consider if the benefits of the enhanced satiety hypothesis can be translated to consumers. In particular this is pertinent as structural manipulations to beverages (reducing oil droplet size) which produce satiety-relevant cues are associated with increased palatability, which could be useful for generating beneficial consumer products (Lett et al., 2016). Additionally, it is likely that expectations influence satiation, and a contributing factor may be the degree to which products are considered healthy. However design limitations in the health halo literature make it unclear whether health beliefs do relate to increased intake, whether they relate to expectations of satiation and satiety and whether mismatches between expectations and sensory experience modulate these effects. These are all important problems to consider if benefits of enhanced satiety and problems with health marketing are to be communicated to consumers.

A recent review suggested that benefits of satiety to consumers are far reaching, including: aiding dietary control strategies through reducing attentional biases to food associated with hunger, and enhancing self-efficacy; by reducing hunger-related dysphoria; and by enabling intake of palatable foods whilst minimising over-eating, given that expected satiety is a better predictor of portion size selection than palatability (Hetherington et al., 2013). Providing products which deliver enhanced satiety could therefore provide significant benefits to consumers. However the literature on cognitive-sensory-nutritional interaction effects on satiety to date should not be generalised beyond the laboratory, making it unclear as to whether this enhanced satiety concept can indeed be beneficial to consumers. This contention is substantiated in the next sections.

#### 1.2.1 Issues with common laboratory approaches

The first contention that consumers are not represented appropriately in the literature is that the reaction to food stimuli may be different outside of a laboratory setting. It is

clear from the research discussed earlier that the situational context in which foods are consumed can generate strong effects on evaluations of those foods. For example studies have demonstrated that identical foods vary in acceptability based on the context in which they were consumed. Identical foods from a restaurant were considered more acceptable than from laboratories, cafeterias, or institutions such as hospitals (Edwards, Meiselman, Edwards, & Leshner, 2003; Meiselman, Johnson, Reeve, & Crouch, 2000). Additionally the perceived suitability of a food for a context influences liking evaluations (Cardello, Schutz, Snow, & Leshner, 2000; King, Weber, Meiselman, & Lv, 2004). Similarly one study demonstrated an interaction between context and perceived suitability in soldiers, where there was a high correlation between liking ratings of snack foods consumed in the field compared to the laboratory, there was little correlation for foods considered as a meal (de Graaf et al., 2005). These studies clearly demonstrate that the context in which foods are consumed can effect evaluations of those foods. In particular consuming foods in laboratories may lead to differential evaluations compared to more realistic meal settings, particularly if the products are deemed unsuitable for that eating context.

Additionally, contextual differences between the laboratory and ordinary eating situations could influence intake. In order to control potential extraneous variables ingestive behaviour studies typically take place in a laboratory where the variables of interest can be isolated. However focussing on individual or small numbers of variables does not represent the context in which foods are consumed by real consumers (Meiselman, 1992a, 1992b; Rozin & Tuorila, 1993). The real context in which foods are consumed consists of many competing sources of sensory stimulation, contextual, and social factors which contribute to product evaluations and intake (Rozin & Tuorila, 1993; Stroebele & De Castro, 2004a; Brian Wansink, 2004). For example contextual influences unrelated to the consumed food *per se* such as listening to music (Bellisle, Dalix, & Slama, 2004; Stroebele & de Castro, 2006), watching television (Bellisle et al., 2004; Stroebele & De Castro, 2004b), and the presence of other people (Bell & Pliner, 2003; De Castro, 1990) have been demonstrated to increase intake. Importantly these contextual variables are likely to represent real-world eating behaviour, although would

largely be controlled in typical studies assessing sensory and nutritional influences on intake. Whilst assessing these variables in isolation in the laboratory is valuable for establishing their influence on intake, it is likely that outside of the laboratory these factors would be experienced simultaneously with the experience of the food and its post-ingestive effects. Therefore true representations of real-world effects must aim to study naturalistic eating contexts as well as laboratory contexts (Meiselman, 1992a, 1992b).

The above examples relate to influences on intake in satiation studies. It is contended here that contextual variables that could represent differences between the laboratory and ordinary eating environments could also influence satiety. Recent studies have investigated the effects of distraction during eating by watching television (Higgs & Woodward, 2009), or playing computer games (Brunstrom & Mitchell, 2006; Oldham-Cooper, Hardman, Nicoll, Rogers, & Brunstrom, 2011). These studies have all demonstrated that being distracted whilst consuming a food reduces its satiating effects, indicated by increased intake of subsequent food and decreased subjective satiety ratings. One possibility for this effect is cognitive controls including memories of previous intake are integrated in the brain with bottom up physiological controls (as argued here in section 1.1). However distraction limits the ability to encode memory for food intake (Higgs, Dolmans, Humphreys, & Rutters, 2015; Higgs et al., 2012; Higgs & Woodward, 2009; Robinson et al., 2013). This idea is consistent with the present integrated approach to satiety. However here it is argued that this could contribute to differences between laboratory-based satiety studies to the experience of satiety beyond the laboratory. This is because there are likely to be greater sources of distraction in less-controlled environments. Some such distractions have already been documented (e.g. watching television, listening to music, the presence of other people). Whilst this requires substantiation it is plausible that realistic eating environments entail more numerous distractions than controlled satiety studies, and therefore could limit the generalisability of laboratory findings to real consumers. As such again this thesis agrees with Meiselman's contention that a balance between laboratory and naturalistic

studies is required in order to assess how food manipulations generalise to real-world populations (Meiselman, 1992b).

To summarise, researchers have noted contextual effects on product evaluations, satiation and satiety measures, suggesting that findings from laboratory studies may not necessarily represent real-world eating behaviour. In particular the less controlled environment beyond the laboratory is likely to involve multiple, simultaneously experienced, influences on appetite, which are often isolated in the laboratory. Whilst the interactive approach of Yeomans and colleagues has begun to assess the interaction between cognitive, sensory and nutritional variables rather than viewing these cues in isolation (Chambers et al., 2013; McCrickerd et al., 2014b; Yeomans & Chambers, 2011; Yeomans et al., 2014), these methods still do not represent all of the cues that could influence eating behaviour in the ‘real-world’. This thesis contends that in order to assess whether the benefits of the enhanced satiety concept can be translated to consumers Meiselman’s approach (Meiselman, 1992a, 1992b) of exploring the findings using real consumers in real eating contexts, alongside laboratory studies, should be adopted.

### 1.2.2 Relevant study populations: cognitive restraint and disinhibition

Meiselman’s contention discussed above (Meiselman, 1992a, 1992b) suggests that, alongside laboratory studies, real people should be studied in real contexts. Section 2.2.1 argued that the enhanced-satiety concept needs to be explored in a naturalistic context. Here the other part of Meiselman’s suggestion is supported: that effects on eating behaviour should be assessed on ‘real people’. There is reason to believe, given that one benefit of satiety may be to help to adhere to dietary goals (Hetherington et al., 2013), that those who are concerned about their diets may be a suitable population for whom enhanced satiety may benefit. This population is represented in the literature by those who report high levels of dietary restraint (discussed below). However, typically, enhanced satiety studies screen for, and recruit, those reporting low restraint (e.g. Chambers et al., 2013; McCrickerd et al., 2012; McCrickerd et al., 2014; Yeomans &



Chambers, 2011; Yeomans et al., 2014). This is generally to guard against floor effects where participants may exercise restraint during the test meal and fail to respond to manipulations. However, in order to explore whether the enhanced satiety concept can be useful outside of the laboratory it must be studied on individuals who would most likely be consumers of products claiming this benefit. The literature regarding this population is discussed in the next sections.

#### 1.2.2.1 Early restraint theory

Dietary restraint concerns the conscious attempts by some individuals to restrict intake due to concerns with health and body image. This idea, originally conceived by Herman and Mack (1975), was a development of Schachter's (1968) externality theory and Nisbett's (1972) set point theory of body weight. Schachter had suggested that obese individuals overate because they were less responsive to internal intake cues and more responsive to external intake cues (such as sensory cues and food availability). Meanwhile, Nisbett suggested that individuals have genetically predisposed body weight set points which drive the individual to maintain a particular body weight, where obese individuals have higher set points. Consequently, Nisbett suggested that individuals could overeat according to societal conceptions of appropriate intake and body weight, whilst under-eating relative to their biological set points. In this case, many obese individuals could actually be below their biological weight disposition, albeit overweight relative to societal views of ideal weight. Herman and Mack (1975) extended these ideas in suggesting that individuals (lean and obese) vary in the degree to which they attempt to restrict their intake, due to societal and health pressures related to body weight, at a level below their biological set point, effectively leaving them food deprived. Thus behaviours that appeared counter-regulatory (such as over-responsiveness to external intake cues), previously explained as obese characteristics, were posited as a consequence of restraint status rather than obesity *per se*. Due to this putative food deprivation, relative to biological set-points, restrained individuals would be prone to overeating if the restraint was broken (an effect known as disinhibition).

A key development of restraint theory was the boundary model (Herman & Polivy, 1983) which suggested that intake is constrained within limits (rather than an absolute set point) by biological necessity, where hunger and satiety promote and inhibit intake respectively. One prediction of the boundary model was that for restrained eaters' greater deprivation and intake are required before hunger or satiety, respectively, are reported. This idea resonates with Schachter's (1968) externality theory although highly restrained, rather than obese, individuals were viewed as being less sensitive to internal appetite cues. An additional prediction of the boundary model was that restrained eaters cognitively impose a diet boundary representing the desired amount of intake, which resides between the limits determined by hunger and satiety cues. Thus a restrained individual would be predicted to initiate eating at a greater degree of deprivation than a non-restrained individual and terminate eating at a cognitively imposed limit before satiety is reached. Finally, the model predicts that if the diet boundary is breached disinhibition occurs and the individual eats until satiety is reached. Disinhibition is also promoted by other challenges to the capacity for cognitive restraint such as stress, depleted self-control, inability to monitor intake, social influence or alcohol intoxication (see Herman & Polivy, 2005; Ruderman, 1986 for reviews).

#### 1.2.2.2 Early empirical support

In the first empirical studies of the restraint hypothesis and the predictions of the boundary model individual variations in cognitive restraint were measured using the restraint scale (Herman & Mack, 1975; later revised in Polivy, Herman, & Warsh, 1978). The restraint scale (RS) is a questionnaire consisting of ten items assessing individuals' weight fluctuations and concern for dieting generating a single restraint score. Early studies using the RS to categorise high and low restrained individuals provided some support for the restraint hypothesis. For example, Herman and Mack (1975) administered either one, two or no milkshake preload to non-obese female participants and measured subsequent intake of an *ad libitum* ice cream course disguised as a taste test. The results suggested that the unrestrained participants reduced their intake following the preloads demonstrating a degree of compensatory response.

However, the restrained participants increased their intake following the preload relative to no preload, and to the greatest extent following two preloads. This study supported the prediction that when restrained participants break a self-imposed dietary boundary they are likely to overeat. Another study using the RS demonstrated that there was no difference between obese and lean participants in intake following a preload, but high scorers on the restraint scale ate more and low scorers ate less following the preload (Hibschler & Herman, 1977). Additionally, free fatty acid levels (a marker of deprivation previously shown to be elevated in obese participants) were higher in restrained than unrestrained participants. These findings supported the idea that overeating is caused by the disinhibition of dietary restraint rather than obesity and that this may be due to relative food deprivation caused by intake restriction. Additionally, several other early studies using the RS support this disinhibition effect in various contexts that limit the capacity for restraint. For example, inducing dysphoric mood led to overeating in restrained but not unrestrained participants (Herman & Polivy, 1975; Ruderman, 1985). Similarly, consuming a believed high calorie (Mills & Palandra, 2008; Polivy, 1976; Spencer & Fremouw, 1979), high volume (Polivy, Herman, & Deo, 2010), or alcoholic (Polivy & Herman, 1976) preload led restrained but not unrestrained participants to consume more regardless of actual preload energy content. Early (and some more recent) studies using the RS therefore suggested that dietary restraint is characterised by overeating (due to food deprivation) when restraint is broken by a disinhibitor.

#### 1.2.2.3 Measurement problems

One major criticism of the early work on restraint (amongst others beyond the scope of this thesis, but reviewed in Ruderman, 1986 and Heatherton et. al. 1988) is that restraint, as measured by the RS, is not a unitary concept. The restraint scale generates a restraint score based on two categories of items – weight fluctuation and dietary concern. Therefore, those scoring highly on the restraint scale are likely to be those susceptible to periodic weight gain, making it unsurprising that they overeat in laboratory experiments. In other words the restraint scale identified a particular type of

restrained eater who is likely to be susceptible to disinhibit (Heatherton, Herman, Polivy, King, & McGree, 1988; Wardle, 1986). It is noteworthy that the connection between restraint and the conditions which promote disinhibition were established on the basis of research using the RS (Heatherton et al., 1988), nonetheless the RS is likely to identify those individuals with a propensity to do so by examining weight fluctuation as part of the measure.

Consequently, two other (now commonly used) questionnaires were developed which measure dietary restraint and tendency to disinhibit on separate scales. The Three Factor Eating Questionnaire (TFEQ; Stunkard & Messick, 1985), and the Dutch Eating Behaviour Questionnaire (DEBQ; Van Strien, Frijters, Bergers, & Defares, 1986). The TFEQ consists of 51 items pertaining to three subscales measuring susceptibility to hunger (which, due to validity issues rarely features in the contemporary literature, see Bond, McDowell, & Wilkinson, 2001) along with restraint and disinhibition. The TFEQ therefore generates a separate score for the degree to which individuals attempt to restrain their intake (TFEQ-R) and the degree to which they are susceptible to disinhibit that restraint (TFEQ-D). The factor structure generated by the design of the TFEQ allowed any one person to score on a restraint subscale and a disinhibition subscale independently. Similarly the DEBQ is a 33 item questionnaire comprised of three subscales allowing individuals to score on measures of restrained eating, emotional eating and external eating. The restraint scales of the TFEQ and DEBQ have been shown to measure restraint similarly, although the relationships between the other factors of the questionnaires are less clear (Van Strien et al., 1986).

Several studies failed to support the hypothesis that a forced preload would lead to overconsumption in restrained eaters reported restraint scores, using the TFEQ or DEBQ (Dritschel, Cooper, & Charnock, 1993; Jansen, Oosterlaan, Merckelbach, & van den Hout, 1988; Lowe & Kleifield, 1988; Ouwens, Van Strien, & Van Der Staak, 2003; Wardle & Beales, 1987; Westenhoefer, Broeckmann, Münch, & Pudiel, 1994). One reason for the inconsistency with the early support for the disinhibition of restraint the RS conflated restraint with the tendency to overeat (as described above) whereas the

TFEQ and DEBQ measured attempts to restrain intake and the tendency to disinhibit separately. As such a high restraint score on these scales did not necessarily predict the tendency to disinhibit. Supporting this notion, a study of the validity of the RS, TFEQ and DEBQ found that the RS represented two factors equivalent to the restraint and disinhibition factors of the TFEQ (Williamson et al., 2007). Additionally Williams and colleagues' study found that energy balance (measured by comparing a body fat composition measure to the level of energy required to maintain stable weight at baseline) was negatively correlated with changes in TFEQ-R in dieting participants (over a 6 month period), suggesting that changes in TFEQ-R are a genuine measure of relative dietary restriction. On the other hand studies have failed to find associations between TFEQ-R and BMI (Dykes, Brunner, Martikainen, & Wardle, 2003). Therefore it is more accurate to consider TFEQ-R a measure of the intent to restrict intake (and a measure of individuals' changes in intake restriction), rather than successful restriction of intake (e.g. Lawson et al., 1995). There is also evidence to suggest that TFEQ-D is a valid measurement of the tendency to overeat. This is indicated by positive relationships between TFEQ-D and BMI (Dykes et al., 2003; French et al., 2014; Gallant et al., 2010), and episodic intake (Lawson et al., 1995; Ouwens et al., 2003).

The above evidence suggests that TFEQ-R and TFEQ-D are likely to represent different constructs measuring the intent to restrict intake and the tendency to overeat respectively. However, it is important to note that the constructs may interact to influence eating behaviour. For example in a modification of the original forced preload experiments (Herman & Mack, 1975) Westenhoefer and colleagues found evidence that counter-regulation was only demonstrated in participants high in restraint and disinhibition, measured by the TFEQ (Westenhoefer et al., 1994). Similarly, overeating in dysphoric states have been reported to a greater degree for individuals scoring high in TFEQ-R and TFEQ-D compared to other combinations of restraint and disinhibition scores (Haynes, Lee, & Yeomans, 2003; Yeomans & Coughlan, 2009). Moreover one study has suggested that the relationship between disinhibition and BMI is moderated by greater TFEQ-R scores (Williamson et al., 1995).

In summary, the evidence described above suggests that contemporary measures of dietary restraint, such as TFEQ-R, measure the intent to restrict intake, whereas the tendency to overeat, TFEQ-D, represents a separate, but interacting, construct. As such the early findings that restrained eaters overeat following forced consumption of a preload may actually represent specific individuals with a tendency to overeat as well as attempt to restrict their intake. As this thesis is concerned with how sensory and contextual information can influence satiation and satiety, the next subsection considers how restraint and disinhibition might influence individuals' reactions to foods exhibiting such cues.

#### 1.2.2.4 The influence of restraint and disinhibition of response to external cues

The initial conception of restraint theory was built upon the idea that restrained individuals would be under-responsive to internal appetite cues and over-responsive to external cues related to foods and the context they are consumed in (Herman & Mack, 1975; Herman & Polivy, 1983). The findings discussed above that restrained eaters, and later restrained eaters who also score highly on TFEQ-D, overeat following a preload or dysphoric mood demonstrate one way in which such individuals fail to respond to internal cues. However there are other examples in which variations in restraint and disinhibition lead to differences in responding to specific attributes or information about foods. Early studies using the RS supported this idea. For example, one study had participants ingest a placebo pill that was presented as hunger or satiety promoting. The results suggested that restrained but not unrestrained participants responded to the false effects by consuming more in the hunger pill condition (Heatherton, Polivy, & Herman, 1989). This study used a no expectation control group, but effects were only found for a difference between the hunger and satiety placebos, making it unclear whether this heightened response to external cues was relevant for enhanced hunger or satiety cues. Additionally unrestrained participants responded in contrast to the placebo message by consuming more in the satiety than the hunger pill condition. This could be related to expectation contrast effects as described above (Yeomans et al., 2008; Zellner et al., 2004). Similarly, Fedoroff, Polivy, & Herman (1997) found that individuals who scored

highly on the RS responded to a greater extent to olfactory (the smell of cooking pizza) and cognitive (the thought of pizza) cues by increasing their intake relative to non-cue conditions. Unrestrained eaters on the other hand did not increase their intake in the cue conditions. Given the above discussions regarding the RS the results of these studies do not represent a clear picture as to whether restraint *per se* or the tendency to disinhibit predict this over-response to external cues. Studies using the TFEQ and DEBQ have produced different results. Yeomans, Tovey, Tinley, & Haynes (2004) demonstrated that individuals scoring highly on TFEQ-R but low on TFEQ-D did not increase their intake in response to palatability cues, whereas those low in restraint but high in disinhibition did. Meanwhile, all groups consumed similar amounts of a bland version of the test meal. These findings suggest that propensity to overeat without restraint, as measured by the TFEQ, may be a risk factor for overeating palatable foods. On the other hand Ogden & Wardle (1990) found that restrained individuals (defined using the DEBQ) reported lower hunger following a believed high calorie preload and higher hunger following a believed low calorie preload, whereas unrestrained eaters responded to the actual energy content. With no measure of disinhibition used here it is unclear as to whether this reactivity to false information about the caloric content consumed would be differentiated by disinhibition status. It appears then that there may be an interaction between dietary restraint and disinhibition on the response to external appetite cues, but their role in satiety response is unclear.

#### 1.2.2.5 An influence of restraint and disinhibition in enhanced satiety?

To summarise the above, it appears that individuals vary in the extent to which they attempt to restrict their intake, and also in the extent to which they are successful in doing so. Moreover, those reporting high dietary restraint, and in some cases only those with a tendency to disinhibit, have been demonstrated to respond to external cues such as palatability, olfactory cues, thoughts of food and information the hunger inducing effects of consuming food, by increasing their intake. Additionally, highly restrained individuals with a propensity to disinhibit may respond to consuming a preload by subsequent overeating rather than reducing intake appropriately. On one hand these

studies demonstrate that variations in restraint and disinhibition are likely to influence how people react to a preload. However, what is considered less often is whether variations in restraint and disinhibition could contribute to enhanced satiety. Studies using explicit messages that could contribute to satiety have failed to use a neutral caloric belief condition making it difficult to determine whether the restrained participants responded differentially to satiety cues, increased appetite cues or both (Ogden & Wardle, 1990). Meanwhile, one study which did use a no message condition only reported differences between hungry and full message conditions, and confounded the contemporary concepts of restraint and disinhibition by using the RS (Heatherton et al., 1989). Thus, it remains unclear as to whether satiety messages may be responded to differentially by individuals varying in restraint and disinhibition. If highly restrained individuals are indeed likely to be over-responsive to sensory and contextual information about foods they may also be more responsive to satiety-relevant information. How restrained individuals with a propensity to disinhibit would react to these cues is unclear.

To date the literature on the cognitive-sensory enhancement of satiety has recruited low restrained participants (e.g. Chambers et al., 2013; Mccrickerd et al., 2012; McCrickerd et al., 2014; Yeomans & Chambers, 2011; Yeomans et al., 2014). However it is contended here that high restrained populations may be likely to react differently to the enhanced-satiety effects, and indeed variations in disinhibition may also influence the effects. Moreover it is likely that those individuals who are concerned about diet control (i.e. restrained eaters) may be more interested in using enhanced-satiety products. This claim needs substantiation, but nonetheless in order to apply the enhanced-satiety concept to real consumers, as suggested by Meiselman (Meiselman, 1992a), it must be assessed in these populations.

### 1.3 Summary and rationale

The above overview demonstrates that appetite control depends upon specific interactions between beliefs about products, the sensory context in which they are



consumed, the post-ingestive effects of the nutritional content and individual characteristics which predict response to satiety cues. Specifically, the match between cognitive and sensory cues that predict satiety and the nutritional content is key for generating satiety. However it is unclear as to whether small energy loads would generate enhanced satiety in the presence of such cues, or whether this would lead to rebound hunger effects. Additionally, limitations of laboratory studies and the populations upon which enhanced-satiety studies have been performed limit our understanding of whether benefits of the enhanced satiety concept would translate to consumers. Finally, satiation is influenced by expectations. One specific case relates to beliefs about the healthiness of products. It has been suggested that believed healthy products are over-consumed, although design limitations of such studies necessitate further research. It is also unclear how healthiness relates to explicit satiety expectations and whether its effects depend on matching expectations with sensory experience. The literature on food acceptability demonstrates clear effects of expectation disconfirmation, but whether this influences intake by modifying expectations about characteristics of products such as healthiness is yet to be explored. Over five studies the present thesis explored these questions, with regards to how benefits of the enhanced satiety concept can be translated to consumers, and the role of expectations in health halo effects.

Study 1 investigated the extent to which sensory enhancements generated enhanced satiety in beverages varying in energy density.

Study 2 investigated the role of sensory enhanced satiety over repeated exposures experienced in consumers' own homes, and assessed consumers' reactions to the enhanced satiety concept.

Study 3 followed the assertions of the focus group from study 2, and investigated how specific groups of consumers would react to enhanced satiety. Specifically this study explored the enhanced satiety concept in a group that has previously been excluded: those reporting high restraint, and varying in the disinhibition dimension. This was

particularly important given that these consumers are most likely to benefit from the enhanced satiety concept yet may react differently to non-restrained individuals.

Finally studies 4 and 5, based on the health-halo concept, assessed whether health information generates beliefs and expectations about the satiating capacity of foods, and whether this influences intake. Additionally these studies explored how health-based expectations are influenced by confirmation or disconfirmation of health information by sensory experience.

## 2 Paper 1: The effects of energy content on satiety in beverages with satiety-predicting sensory properties

### 2.1 Abstract

Recent research suggests that by providing satiety cues (viscosity and creamy flavours) in beverages can enhance satiety. This is pertinent given that beverages are thought to be associated with weak satiety responses, yet this research offers insight into how beverage products with a high satiety value might be developed. However the research has also demonstrated that the presence of these satiety cues in beverages with low energy content does not enhance satiety and can even lead to greater hunger (rebound effects). The present study aimed to assess the extent of covert energy addition required to deliver enhanced satiety in beverages with orosensory cues. This study used a within-subjects preload design to test behavioural and subjective satiety responses to enhanced and non-enhanced beverages varying in energy content. The results failed to replicate earlier enhanced satiety results as enhanced beverages did not deliver greater subjective satiety or decreased subsequent intake. However energy compensation for lower-energy content beverages did not clearly differ from perfect (100%; as assessed by a Bayes factor). This is taken as preliminary, tentative evidence that lower-energy sensory enhanced beverages can deliver appropriate compensatory intake adjustments and avoid rebound effects. Given the unclear findings this needs to be further substantiated, although can be considered a possibility for future research.

## 2.2 Introduction

Understanding the factors that influence satiety, the system involved in suppressing appetite following ingestion (Blundell, Lawton, Cotton, & Macdiarmid, 1996), has become an increasingly important area of study as researchers attempt to understand the growing obesity crisis (Mozaffarian et al., 2015). Additionally, satiety potentially has many benefits to consumers including promoting adherence to dietary goals and reducing hunger-related dysphoria which may contribute to a wider range of factors that dissuade overeating (see Hetherington et al., 2013 for a review). According to Blundell's Satiety Cascade (e.g. Blundell et al., 1996) cognitive and sensory cues can influence satiety along with post-ingestive and post-absorptive factors. However, it is less clear how these factors interact to generate the satiety experience, and whether the satiety delivered can be optimized for maximal satiety benefits to consumers.

Animals possess a complex of physiological mechanisms which respond to the ingestion of nutrition to generate satiety responses (as reviewed by Woods, 2004). However, laboratory studies often report that people do not compensate accurately for consumed energy by reducing their subsequent intake appropriately. For example, a recent systematic review of 253 studies demonstrated a median compensation score of 62% of the energy consumed accounted for by reduced intake at a subsequent meal (Almiron-Roig et al., 2013). In particular, studies exploring the role of food form in satiety and satiation have demonstrated a relatively poor compensatory response to calories consumed in beverages and semi-solid foods compared to equicaloric solid equivalents (DiMeglio & Mattes, 2000; Flood-Obbagy & Rolls, 2009; Mattes, 1996; Mourao et al., 2007). Moreover, weaker subjective reports of satiety have been demonstrated following liquid preloads than solids or semi-solids (Hulshof et al., 1993). Whilst some studies have not found this weaker satiety effect following liquid preloads (e.g. Almiron-Roig, Flores, & Drewnowski, 2004; Drewnowski, Flores, & Almiron-Roig, 2004), Almiron-Roig and colleagues' (2013) review found a weaker median compensation score (43%) in studies using beverage preloads than solids or semi-solids.

One explanation for this effect is that beverages are associated with a relatively short oral exposure time (de Graaf, 2011, 2012). This may be associated with a poorer ability to learn the association between sensory properties and the consequences of ingestion (Mars et al., 2009), and weaker satiety relevant feedback from anticipatory (cephalic phase) physiological responses (de Graaf, 2011). These findings and theories suggest that beverages provide a context for ingestion of energy that does not predict satiety.

Conversely, evidence suggests that consuming beverages in contexts that predict satiety generates stronger actual satiety. For example: liquids framed as soups deliver greater satiety than the same ingredients consumed as beverages (Mattes, 2005), beliefs that a beverage is thirst-quenching result in weaker compensation than when framed as filling (McCrickerd et al., 2014b), and the belief that a food would become or remain liquid in the gut decreased ghrelin suppression, and reduced glucagon-like peptide 1 and insulin release to a greater degree than if people believed that it would become or remain solid (Cassady et al., 2012). Additionally sensory properties that predict satiety are associated with greater satiety. This has been demonstrated by the finding that the enhanced satiating capacity of protein relative to other macronutrients was dependent on sensory properties predicting protein content such as viscosity and creamy flavours (Bertenshaw et al., 2013), and umami flavours which may signal protein content (Masic & Yeomans, 2014). Viscosity in particular has been posited as an important cue for satiety given that breast milk viscosity is associated with energy density (Picciano, 1998) so humans may learn this association early in life (Chambers et al., 2015). Several studies support the relative satiating capacity of more viscous liquids (Zijlstra, De Wijk, Mars, Stafleu, & De Graaf, 2009; Zijlstra et al., 2009; Zijlstra, Mars, Stafleu, & de Graaf, 2010), and viscosity is associated with greater expected satiety, suggesting this characteristic could be involved with anticipating satiety (Hogenkamp et al., 2011; McCrickerd et al., 2012). These studies suggest that beliefs about satiety and predictive satiety cues may generate greater satiety responses.

A recent series of studies however has suggested that the extent to which satiety-relevant cues generate greater satiety is dependent upon the match with appropriate energy delivery. When sensory cues (enhanced viscosity and creamy flavours) are provided consumers compensate more accurately by reducing their intake of a subsequent meal (Chambers et al., 2013; McCrickerd et al., 2014b; Yeomans & Chambers, 2011; Yeomans et al., 2014). However, if these cues are present in the absence of energy higher hunger ratings and intake can occur (McCrickerd et al., 2014b; Yeomans & Chambers, 2011). One explanation for this is that preparatory satiety responses are generated in expectation of nutrient delivery which does not arrive, leaving the body prepared to ingest (see Chambers et al., 2015). Thus whilst this cognitive-sensory enhancement of satiety could be beneficial to consumers by reducing hunger dysphoria and increasing the chance of adherence to dietary goals (see Hetherington et al., 2013) it is unclear whether this is achievable in low-energy products. The typical strategy for diet product development, to maximise sensory similarity with higher energy products whilst minimizing caloric content, may therefore be counter-productive in the light of these arguments and may fail to benefit consumers (see Yeomans, 2015).

In order to explore the extent to which sensory cued satiety does benefit consumers the present study examined the effects of small energy additions to beverages with enhanced orosensory cues. The previous studies from Yeomans' laboratory observed enhanced satiety effects with a lower and upper energy limit of 78 kcal and 279 kcal respectively. Sensory cues provided for the 78 kcal beverage failed to reduce intake, and even generated 'rebound' hunger effects (Yeomans & Chambers, 2011). In the present study, we introduced two intermediate energy-containing beverages in order to explore the extent of energy reduction that can be tolerated in sensory-enhanced beverages whilst maintaining satiety. Almiron-Roig and colleagues' (2013) systematic review found a negative correlation between energy compensation and preload energy content, suggesting that people compensate more accurately for smaller energy loads. However, this effect was driven by studies using solid and semi-solid preloads and not liquid

preloads. Thus, it is unclear whether compensation for small energy additions to beverages would be more accurate than high-energy loads when presented in an enhanced sensory-context. Therefore, we hypothesised that satiety could be maximised by the presence of enhanced-sensory characteristics in high-energy beverage preloads, and we explored whether two intermediate energy beverages would generate satiety in this enhanced sensory-context.

## 2.3 Method

### 2.3.1 Design

A within-participants design tested the effect of six beverage preloads differing in the combination of energy and sensory characteristics on subjective satiety ratings and subsequent intake of a two-course *ad libitum* test meal. The preloads were consumed in two sensory contexts: High (enhanced) sensory (subsequently written as HS; thick texture and creamy flavours), and low (non-enhanced) sensory (LS), and four energy loads: High-energy (HE), low-energy (LE), 33% (33) and 66% (66) of the energy difference (Table 2.1). The LE and HE preloads were consumed in both sensory contexts, and the 66% and 33% preloads were only consumed in the HS context. Participants consumed the preloads in a counterbalanced order using a Williams Square design.

*Table 2.1 Six beverage preloads were consumed by participants. These varied in energy content and sensory context. Four preloads were presented with thick and creamy sensory characteristics and low and high energy control preloads were presented without these sensory enhancements.*

Non enhanced	Enhanced sensory
Low energy (LE)	High sensory / Low energy (HSLE)
	High sensory/ 33% energy (HS33)
	High sensory/ 66% energy (HS66)
High energy (HE)	High sensory/ High energy (HSHE)

### 2.3.2 Participants

Eighteen males and 18 females were recruited for a study of food and mood. This sample size was based on an *a priori* power analysis, which suggested that 28 participants would be sufficient to observe a medium effect size ( $f = .25$ ) with strong power ( $\beta = .95$ ,  $\alpha = .05$ ). Previous studies have reported medium within-participants energy compensation effects between high and low sensory conditions ( $f = .29$  in Yeomans & Chambers, 2011), but presently a more conservative estimate was employed to account for intermediate energy conditions. Exclusion criteria were: high restraint (greater than seven on pre-test Three Factor Eating Questionnaire (TFEQ; Stunkard & Messick, 1985); current dieting; smoking > five cigarettes per week or using nicotine replacements; taking prescription medicines other than the contraceptive pill; allergies or aversions to the test ingredients; pregnancy or lactating women; diabetes or diagnosed eating disorders. Informed consent was obtained, and course credits or £60 were offered for participation.



### 2.3.3 Materials

#### 2.3.3.1 Visual Analogue Scales

Subjective satiety ratings were collected using computerised 100pt visual analogue scales (VAS), presented using the Sussex Ingestion Pattern Monitor (SIPM) software (Yeomans, 2000). Appetite and dummy mood ratings (hunger, fullness, desire to eat, thirst, anxious, calm, clear-headed, energetic, happy, headache, nauseous, and tired) were collected pre and post-preload, pre-lunch, post-taste of the *ad libitum* test meal course one, post-test meal course one, post-taste of the test meal course two, and post-test meal course two. The rating questions were presented in the format “how <rating> do you feel?” anchored by “not at all <rating>” and “extremely <rating>”. Following preload tasting sensory ratings (thick, creamy, pleasant, sweet, fruity, familiar, sour, and filling) were collected in the format “how <rating> is the beverage?” anchored as above. Additionally, sensory ratings (course one: bitter, sweet, salty, sour, spicy, familiar and pleasant; course two: bitter, sweet, creamy, familiar and pleasant) of the test meal were presented as “how <rating> is the pasta/ ice cream?” anchored as above. The rating order in each section was randomised.

#### 2.3.3.2 Standardised Breakfast

A standard breakfast of commercially available cereal (Crunchy Nut Cornflakes: Kellogg’s UK.) served in a white ceramic bowl, a serving of semi-skimmed milk (Sainsbury’s Plc. UK) served in a white ceramic mug, and a glass of smooth orange juice (Sainsbury’s Plc. UK) was provided (see Table 2.2). Participants consumed the entire breakfast in a laboratory waiting room.

#### 2.3.3.3 Beverage Preloads

Six beverage preloads based on previous satiety studies that demonstrated reliable rating differences between high and low sensory characteristics (Yeomans & Chambers, 2011;

Yeomans, Chambers & Ells, 2012; McCrickerd et al., 2012) were piloted. Participants adhering to the inclusion criteria above ( $n = 12$ ) rated the sensory characteristics (thick, creamy, pleasant, sweet, fruity, sticky, filling, familiar and sour) of 20g portions of the beverages using the VAS format as above. Ratings were conducted twice on each beverage in a random order. No significant differences between preloads or rating time (first or second taste) were found for pleasant, sweet, sour, or fruity (all  $p > .05$ ). A main effect of preload, but not rating time was found for filling ( $p < .001$ ). LS beverages were rated as less filling than HS beverages ( $p < .05$ ), but did not differ from each other, and the HS beverages did not differ from each other (all  $p > .05$ ). Effects of rating time and preload, were found for familiar ( $p < .05$ ), but no interaction and no differences between the preloads were found (all  $p > .05$ ). There was an effect of preload ( $p < .05$ ) but not rating time ( $p > .05$ ) for sticky with HS beverages tending to be rated as stickier than low sensory beverages, but contrasts found no differences between beverages (all  $p > .05$ ). A main effect of preload was found for creamy ( $p < .05$ ), with HS beverages rated as creamier. There were no differences between LS ( $p > .05$ ) or HS beverages ( $p < .05$ ) except that the HShe beverage differed from the HS33 ( $p < .05$ ). An effect of preload but not time was found for thickness ( $p < .05$ ), and the interaction was significant ( $p < .05$ ). All HS beverages differed from the non-enhanced beverages ( $p < .05$ ). The HShe preload was rated as less thick than other HS preloads on the second rating ( $p < .05$ ) but not the first rating ( $p > .05$ ). The piloted beverages were selected for the main study given that this subtle effect was only present on second tasting.

In the main study the preloads were served in 320g portions in a transparent glass, and consisted of a base containing Tropicana Mango Peach and Papaya Juice (PepsiCo, UK), Robinson's peach squash (Britvic, UK), Normandy Natural Fromage Frais (Sainsbury's Plc. UK) and water. Sensory enhancements were achieved by the addition of tara gum (Kaly's Gastronomie, FR): a soluble thickening agent, milk caramel flavouring (Symrise GmbH), and vanilla extract (Nielsen-Massey, NL) to enhance thickness and creaminess. Energy manipulations were achieved through the addition of maltodextrin (Cargill): a soluble carbohydrate. A graded addition of aspartame

(Ajinomoto Sweeteners, Europe) was added to the LE, HS33 and HS66 beverages accounting for the subtly sweet taste of maltodextrin to match the beverages for sweetness. The beverages were colour-matched by adding red and yellow food colourings (Silverspoon, UK) (Table 2.3).

#### 2.3.3.4 Test lunch

An *ad libitum* test lunch of Conchiglie pasta shells (Sainsbury's Plc. UK) with tomato and basil sauce (Sainsbury's Plc. UK), followed by Carte D'or vanilla ice cream (Unilever, UK) was provided (Table 2.2). The pasta was cooked for 12 minutes in boiling water, washed and left to stand before portions of 200g sauce and 250g cooked pasta were heated for three minutes in a microwave prior to serving. The pasta was presented in white ceramic bowls which were refilled every time participants consumed 350g such that the bowl could never be consumed entirely. Ice cream was served in white ceramic bowls, initially in a 150g portion, followed by 100g refills following consumption of 100g. The weight of food consumed was calculated by the Sussex Ingestion Pattern Monitor (SIPM) software that takes stable weight recordings from a concealed balance every two seconds (Yeomans, 2000).

*Table 2.2 - macronutrient breakdown of a standardised breakfast consumed at the beginning of each test day, and the 2 course test lunch consumed 30 minutes following the preload. The test lunch was consumed ad libitum and therefore the below figures relate are per 100g.*

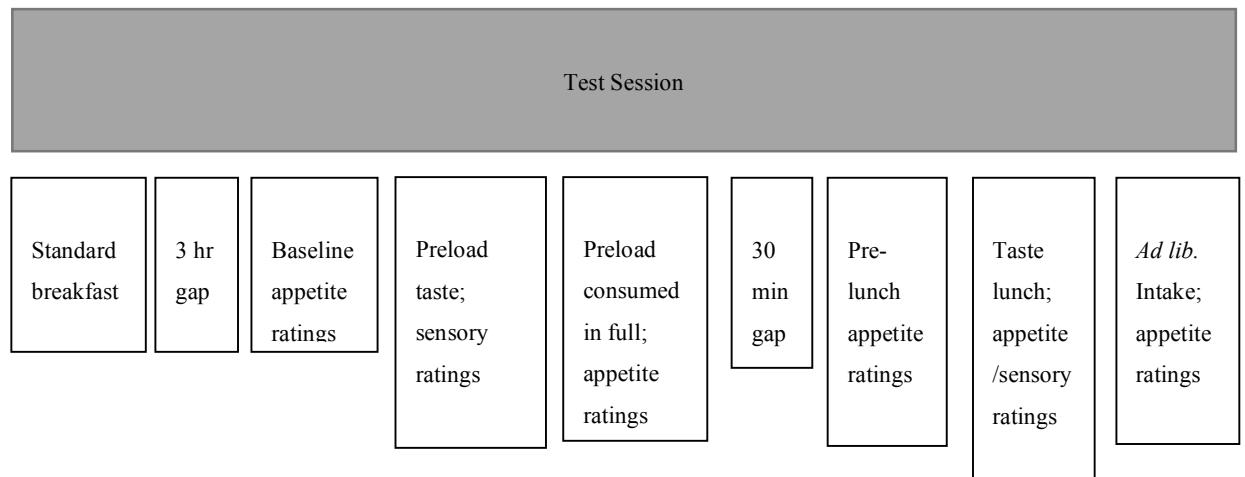
	Amount (g)	Kcal	Carbohydrate	Protein	Fat
Standardised breakfast					
Crunchy Nut Cornflakes	60	241	49	4	3
Semi-Skimmed Milk	160	77	7	6	3
Orange Juice	200	84	17	1.2	1
Total		402	73	11.2	7
Test lunch per 100g					
Pasta (cooked weight)		160	34	4.4	0.6
Tomato Sauce		58	7	1.6	2.5
Total	per 100g	115	22	3.2	1.4
Ice cream per 100g					
Ice cream	per 100g	197	30	2.6	7.4

*Table 2.3– Ingredients and macronutrients for six beverage preloads consumed by participants prior to a test meal (grams per beverage). The preloads varied in sensory characteristics (achieved through additions of tara gum, vanilla essence, and milk caramel) and energy content (maltodextrin).*

	HSHE	HSLE	HS33	HS66	LSHE	LSLE
<b>Ingredients</b>						
Mango Peach and Papaya Juice	100	100	100	100	100	100
Peach Squash	35	35	35	35	35	35
Fromage Frais	30	55	47	38	30	55
Tap Water	98	128	118	109	100	130
Maltodextrin	55	0	18.15	36.3	55	0
Tara Gum	1.3	1.4	1.4	1.3	0	0.2
Vanilla Essence						
Milk Caramel Flavouring	0.8	0.8	0.8	0.8	0	0
Aspartame	0	0.03	0.02	0.01	0	0.03
<b>Macronutrients</b>						
Carbohydrates	63.8	12.6	29.5	46.4	63.8	12.6
Protein	3.0	5.0	4.3	3.6	3.0	5.0
Fat	0	0.1	0.1	0	0	0.1
Energy Content (Kcal)	271.9	75.4	140.3	204.8	271.9	75.4

#### 2.3.4 Procedure

Eligible participants were contacted by email and invited to take part in a food and mood experiment. They were instructed to consume nothing but water from 23.00hrs the evening before each session. Participants attended the laboratory at an arranged time between 08.30hrs and 10.30hrs to consume the standard breakfast in full, before a three-hour interval in which they refrained from eating, drinking (excluding water), or engaging in exercise. Upon returning to the laboratory mood and appetite was rated and one of the beverage preloads was tasted and rated on sensory dimensions, and subsequently consumed fully in no longer than ten minutes. Further mood and appetite ratings were then completed, before participants waited in the laboratory waiting room for 30 minutes: an inter-meal interval that has previously been effective in generating sensory and energy effects in beverages (see Almiron-Roig et al., 2013 for a review). Participants then completed mood and appetite ratings before tasting and rating a sample of pasta and tomato sauce (20g) on sensory characteristics, and further appetite ratings. A 450g bowl of pasta and sauce was then provided for participants to consume *ad libitum* which was placed on top of a balance concealed by a place mat. Following consumption of 350g the SIPM software instructed participants to stop eating and call the experimenter for a refill. This 350g refill procedure repeated until participants indicated that they were comfortably full. Mood and appetite ratings were then administered. A sample of vanilla ice cream (15g) was then tasted and rated on sensory characteristics, and further appetite and mood ratings were made. A 150g bowl of ice cream was consumed *ad libitum*, following the same refill procedure as course one, refills of 100g were provided following consumption of 100g. Final mood and appetite ratings were then administered to end the session. This procedure was repeated on non-consecutive days, with no more than two sessions in one week, with only the beverage preload differing on each occasion until each beverage condition had been completed (Figure 2.1).



*Figure 2.1 test day procedure, repeated for each preload on non-consecutive days in a counterbalanced order. Participants first completed attended a test session and consumed a standardised breakfast followed by a 3-hour interval. Following this, appetite ratings were completed, and a preload was tasted and its sensory characteristics rated. The preload was consumed in full and appetite ratings completed before a 30-minute interval. Following further appetite ratings, a test lunch was administered. The session finished with final appetite ratings. This procedure was completed for each of six beverage preloads.*

### 2.3.5 Analysis

The analysis aimed to explore two key questions: were previous findings that sensory enhancements improved satiety in high-energy beverages replicated, and to what extent did intermediate energy additions to enhanced sensory beverages generate satiety. The satiety generated by sensory enhancements was tested by a two-way two (sensory: HS and LS) by two (energy: HE and LE) repeated-measured analysis of variance (ANOVA). In order to measure the influence of intermediate-energy in HS beverages total and within course *ad libitum* intake was compared between preload conditions using a one-way ANOVA (preload: LE, HSLE, HS33, HS66, HSHE, HE). The intermediate-energy beverages (HS33 and HS66) were compared to the HSLE and HSHE as negative and positive controls respectively to assess the extent of intake suppression by these energy loads in the HS context. Additionally, energy compensation was calculated as the reduction in intake following each energy-added preload relative to the LE preloads, as a percentage of the energy difference between the preloads. Previous studies have reported compensation values relative to the context in which the drink was consumed (Chambers et al., 2013; McCrickerd et al., 2014b; Yeomans & Chambers, 2011), however given our hypothesis that the high sensory context may increase intake following low energy beverages this would inflate the HSHE compensation score. As a result, it would be difficult to separate the effect of increased intake following the sensory enhanced low-energy beverages from decreased intake following sensory enhanced high-energy beverages. Thus, the results report compensation relative to both sensory contexts of the low energy preloads for comparison. Compensation was contrasted across beverage conditions using a one-way repeated measures ANOVA (preload: HS33, HS66, HSHE, HE). Additionally one-sample t tests compared compensation for each preload to 100% (a score that would indicate perfect compensation). For these analyses Bayes Factors (B) were calculated. This statistic quantifies the relative likelihood of the null versus the experimental hypothesis given the data, thus guiding interpretation of the extent to which non-significant results support the null hypothesis (see Dienes, 2014). Dienes suggests that



values of  $\leq 0.3$  constitute support for the null hypothesis, whilst values of  $\geq 3$  support the experimental hypothesis (values between suggest insensitivity to distinguish between the hypotheses). Prior estimates of values that would support the experimental hypothesis are required in order to assess its support from the data. Presently we based this on previous differences from 100% by HS preloads found in Yeomans and Chambers' (2011) study ( $M = 13\%$ ). We introduced a little more leeway (to 20%) as it is not clear whether 13% is a true difference from 100%. Therefore the Bayes factor indicates the strength of support for the hypothesis that the beverages differed by  $\pm 20\%$  from perfect compensation. Additionally for differences between the preloads previous studies have found differences between sensory conditions of between 50-70% (e.g. Yeomans & Chambers, 2011; Chambers, Ells & Yeomans, 2013) so this was used to estimate likely values for Bayes factors with key non-significant compensation differences. VAS appetite ratings were contrasted across preloads using a two-way six (rating time: excluding post-lunch) by six (preload) ANOVA, and the sensory characteristics of the preloads were contrasted using a one-way ANOVA in order to establish whether the key manipulations were successful and that the beverages were matched in other sensory dimensions. Sex was included as a factor in analyses and is reported where it influenced the effects. The standard errors reported were adjusted for repeated-measures variation. The analysis excluded outliers falling two standard deviations from mean intake scores within beverage conditions and gender group. In this study, and throughout the thesis, statistical analyses were conducted using IBM SPSS 22. Bayes factors were conducted using Dienes' online Bayes factor calculator ([http://www.lifesci.sussex.ac.uk/home/Zoltan\\_Dienes/inference/Bayes.htm](http://www.lifesci.sussex.ac.uk/home/Zoltan_Dienes/inference/Bayes.htm); see Dienes, 2014). This calculator computes the likelihood of the observed mean difference given the researchers' suggested prior estimates of meaningful effect size and probability distribution predicted by the theory at test. The estimates researchers input specify the range of plausible values that are consistent with the theory and therefore allow analysis of the likelihood that the observed value (given its standard error) is consistent with the theory.

## 2.4 Results

Eight outliers (five females and three males) were removed, leaving  $n = 28$ . Subsequently all intake scores within sex groups were normally distributed.

### 2.4.1 Intake

#### 2.4.1.1 Sensory-nutrient interactions

Sensory-enhancements did not enhance satiety response (Figure 2.2). This was supported statistically across courses by a large effect of preload energy,  $F(1, 26) = 12.16, p = .002, \eta^2_p = .32$ , but not of sensory context,  $F(1, 26) = 0.48, p = .493, \eta^2_p = .02$ , and no interaction,  $F(1, 26) = 0.32, p = .576, \eta^2_p = .01$ , on total lunch intake. Intake was lower following the HE beverage in the high sensory context,  $t(27) = 2.26, p = .032$ , and the low sensory context,  $t(27) = 3.18, p = .004$ . Males consumed more than females,  $F(1, 26) = 23.26, p < .001, \eta^2_p = .47$ , but this did not interact with energy or sensory context, (both  $p < .486, \eta^2_p < .02$ ). The same pattern emerged for the first and second course. There was a significant effect of preload energy on amount consumed of the pasta course,  $F(1, 26) = 4.55, p = .042, \eta^2_p = .15$ , and a larger effect for the ice cream course,  $F(1, 26) = 12.99, p = .001, \eta^2_p = .33$ , but no effects of sensory context (both  $p \leq .432, \eta^2_p \leq .02$ ), and no interactions (both  $p \leq .48, \eta^2_p \leq .02$ ).

#### 2.4.1.2 Lunch Intake following energy-reduced preloads

Across all preloads *ad libitum* intake differed depending on which preload was consumed (Figure 2.2a),  $F(5, 130) = 2.37, p = .043, \eta^2_p = .08$ . However, intake following the HS33 and HS66 preloads did not differ from each other or the HSLE or HSHE preloads, (all  $p \geq .137$ ). A significant effect of sex was found,  $F(1, 26) = 20.67, p < .001, \eta^2_p = .44$ , with males consuming more than females, but this did not interact with preload,  $F(5, 130) = .65, p = .66, \eta^2_p = .02$ . When pasta intake was analysed

individually no significant effect of preload was found,  $F(5, 130) = 1.01, p = .41, \eta^2_p = .04$ . However ice cream intake depended on preload,  $F(5, 130) = 2.86, p < .05, \eta^2_p = .10$ . Intake was significantly higher following the HS33 than the HSHE,  $t(27) = 2.22, p = .035$ , and following the HSLE than the HS66,  $t(27) = 1.41, p = .047$ , but neither intermediate beverage differed from any other beverages (all  $p \geq .149$ ).

#### 2.4.1.3 Energy Compensation

Unexpectedly, the high sensory context did not enhance compensation for the covert energy additions, and whilst reducing the energy to 33% generated greater compensation, the preloads did not differ statistically (Figure 2.2b). There was no significant effect of preload, on energy compensation relative to the LSLE preload,  $F(1.59, 41.22) = 0.26, p = .72, \eta^2_p = .01$ , or the HSLE preload,  $F(1.64, 42.67) = 0.46, p = .60, \eta^2_p = .02$ . A Bayes factor of 0.19 tended towards support for no difference between compensation scores of the HE preloads, calculated relative to their sensory-matched LE controls. However, whilst the HSHE, and LSHE preloads differed significantly to 100% compensation relative to both LE preloads (all  $p \leq .05$ ), the HS33 preload did not, relative to the LSLE,  $t(27) = .58, p = .555, B = 0.99$ , or the HSLE,  $t(27) = .46, p = .65, B = 0.98$ . The HS66 was trending towards significantly different to 100% relative to the LSLE and HSLE ( $p = .075$  and  $p = .072$ ;  $B = 1.14$  and  $B = 1.17$  respectively). These Bayes factors indicate no clear support for the null hypothesis (i.e. that compensation differed from 100%), but also no support for the hypothesis that the difference was as great as previous studies (estimated as 20%).

#### 2.4.1.4 Test meal pleasantness

Neither the first or second course differed by preload condition in pleasantness ratings (both  $p \geq .085, \eta^2_p \leq .07$ ), suggesting that palatability did not drive intake effects.

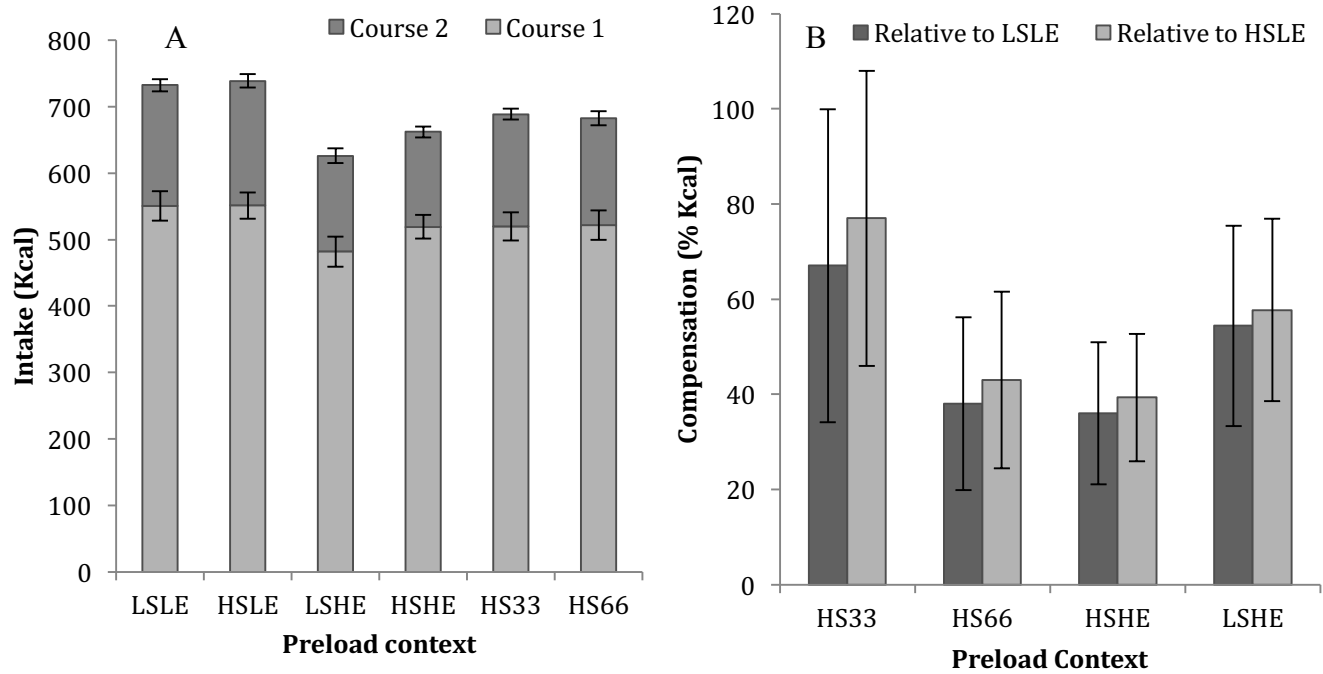


Figure 2.2 A) Preloads varying in energy content and sensory characteristics differed in test meal intake (Kcal). There were significant effects of preload energy content, but not sensory characteristics, on lunch intake between the high and low sensory and energy preloads. Effects were larger for ice cream intake (dark grey bars). The intermediate-energy (HS33 and HS66) preloads did not differ from each other or other preloads. B) There were no significant differences between preloads in energy compensation relative to LSLE and HSLE preloads. The HE preloads, but not the HS33 or HS66 preloads, differed significantly from 100% compensation, Bayes factors indicated insensitivity to determine a difference from 100% compensation for the HS33 and HS66 preloads. Error bars indicate SEM.

#### 2.4.2 Appetite Ratings

As suggested by Figure 2.3, participants reported different hunger, fullness, desire to eat and thirst levels at different times throughout the session (all  $p \leq .001$ ,  $\eta^2_p \geq .33$ ), but this did not differ by preload condition, (all  $p \geq .159$ ,  $\eta^2_p \leq .06$ ), and there were no interactions (all  $p \geq .171$ ,  $\eta^2_p \leq .05$ ) for any rating.

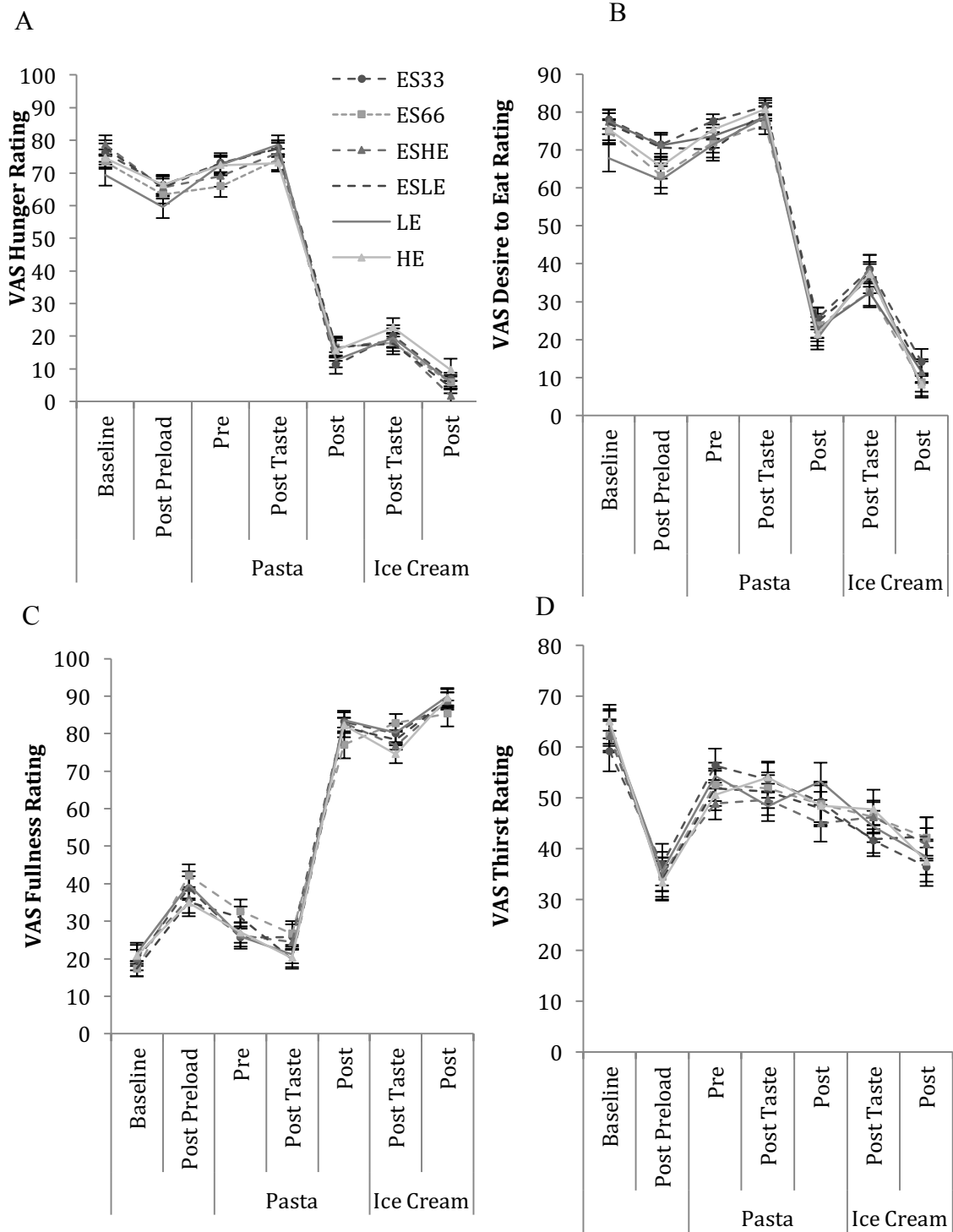


Figure 2.3 There were differences across the test session, but not between preloads in mean VAS appetite ratings throughout the session (error bars represent  $\pm$  SEM. Panels: A) hunger B) fullness C) desire to eat D) thirst).

### 2.4.3 Preload sensory characteristics

The key sensory characteristics of the preloads were compared (Table 2.4). As expected the preloads differed appropriately in key domains and did not differ where designed to match. No differences were found between the preloads for pleasantness or familiarity (both  $p \geq .431$ ,  $\eta^2_p \leq .03$ ). There were differences between the preloads in filling ratings,  $F(2.97, 80.24) = 10.42$ ,  $p < .001$ ,  $\eta^2_p = .28$ . The HSHE was more filling than the LSHE,  $t(27) = 2.63$ ,  $p < .014$ , and the HSLE was more filling than the LSLE,  $t(27) = 3.61$ ,  $p = .001$ . The HS33 was no more filling than the HSLE,  $t(27) = 0.80$ ,  $p = .430$ , but the HS66 was rated as more filling,  $t(27) = 2.51$ ,  $p = .018$ , and both the HS33 and HS66 were more filling than the LSLE,  $t(27) = 3.87$ ,  $p = .001$ , and,  $t(27) = 5.66$ ,  $p < .001$ , respectively but did not differ from one another,  $t(27) = 1.67$ ,  $p = .106$ . The preloads also differed in creaminess,  $F(5, 135) = 20.48$ ,  $p < .001$ ,  $\eta^2_p = .43$ . As expected the HSHE was creamier than the LSHE,  $t(27) = 6.34$ ,  $p < .001$ , and the HSLE was creamier than the LSLE,  $t(27) = 4.95$ ,  $p < .001$ . Additionally, the HS33 and HS66 did not differ,  $t(27) = .72$ ,  $p = .477$ , and neither differed from the HSLE,  $t(27) = 1.79$ ,  $p = .085$  and,  $t(27) = 0.79$ ,  $p = .439$ , respectively, and both were creamier than the LSLE,  $t(27) = 2.81$ ,  $p < .001$ , and,  $t(27) = 3.99$ ,  $p < .001$ . As predicted the preloads differed in thickness ratings,  $F(2.63, 71.05) = 28.90$ ,  $p < .001$ ,  $\eta^2_p = .52$ . The HSHE was thicker than the LSHE,  $t(27) = 6.17$ ,  $p < .001$ , and the HSLE was thicker than LSLE,  $t(27) = 4.45$ ,  $p < .001$ . The HS33 and HS66 did not differ,  $t(27) = 0.44$ ,  $p = .662$ , but unexpectedly the HS33,  $t(27) = 3.03$ ,  $p = .005$ , and the HS66,  $t(27) = 3.64$ ,  $p = .001$ , were thicker than the HSLE, but both were thicker than the LSLE,  $t(27) = 6.54$ ,  $p < .001$ , and  $t(27) = 6.18$ ,  $p < .001$ , respectively.

*Table 2.4 - VAS rated preload sensory characteristics (SEM). There were no differences between the preloads in terms of familiarity, pleasantness, fruitiness, sourness or sweetness. The sensory-enhanced beverages were rated as creamier, thicker and more filling than their unenhanced controls but not the other sensory-enhanced beverages (other than the HSLE which was thicker than the intermediate-energy beverages).*

	Creamy*	Thick*	Filling*	Familiar	Pleasant	Fruity	Sour	Sweet
LE	61.1 (3.3)	56.2 (3.6)	52.2 (2.1)	76.6 (3.5)	84.3 (2.1)	84.1 (1.8)	33.6 (3.0)	77.4 (1.4)
HSLE	81.8 (2.1)	77.8 (2.2)	64.5 (1.8)	78.3 (3.9)	84.2 (1.4)	78.6 (2.0)	28.4 (2.4)	75.6 (1.9)
HE	43.1 (3.5)	43.1 (3.7)	48.0 (3.2)	81.4 (2.9)	87.3 (1.9)	85.7 (1.5)	24.8 (2.3)	80.0 (1.2)
HSHE	76.4 (2.1)	78.3 (2.6)	61.8 (2.2)	80.3 (3.3)	84.5 (1.5)	83.0 (1.8)	27.7 (2.4)	80.5 (1.2)
HS33	75.1 (2.5)	85.1 (1.5)	66.4 (1.4)	83.8 (2.8)	83.9 (1.7)	79.7 (1.6)	23.7 (2.0)	77.2 (1.4)
HS66	78.8 (2.7)	86.1 (1.9)	71.2 (2.1)	77.9 (3.6)	81.3 (1.8)	76.5 (2.2)	27.9 (2.9)	76.7 (1.2)

\* significant effect of preload condition ( $p < .05$ )

## 2.5 Discussion

The present study examined the degree to which small carbohydrate energy additions to beverage preloads would generate satiety when consumed in an enhanced sensory context. This was designed to shed light on whether consumers can benefit from enhanced satiety in products which deliver a smaller energy loads and thus may be useful for dietary management. The logic behind this question was that whilst energy compensation in general is more accurate for lower-energy preloads this is not the case for beverages (see Almiron-Roig et al., 2013). However compensation in beverages can be improved by providing orosensory cues to the presence of energy (Chambers et al., 2013; McCrickerd et al., 2014b; Yeomans & Chambers, 2011; Yeomans et al., 2014), although the same cues in low-energy preloads can lead to increased hunger and intake

(McCrickerd et al., 2014; Yeomans & Chambers, 2011). Presently we found that whilst higher-energy preloads suppressed intake the sensory enhancements failed to modulate this effect and there was no evidence of rebound effects in the low-energy beverage. The reduced intake following covert high-energy beverages supports a role of post-ingestive feedback generating satiety (see Woods, 2004 for a review). However, energy compensation was inaccurate. The 33% energy enhanced sensory beverage generated greater compensation than higher-energy preloads, but not significantly so. Neither of the intermediate-energy beverages differed significantly from 100% (perfect) compensation. Bayes factors demonstrated that the difference from 100% compensation was not clearly present or absent. Therefore, it remains a tentative possibility that compensation for small energy additions in sensory-enhanced beverages is relatively accurately. Satiety-relevant orosensory characteristics did not improve compensation for high-energy preloads, and a low Bayes factor further supported this. Similarly, there were no differences between the preloads on subjective appetite ratings. Given the similar nature of the participants, stimuli and procedure to former studies which demonstrated an enhanced satiety or satiation effect (Chambers et al., 2013; McCrickerd et al., 2012, 2014a, 2014b; Yeomans & Chambers, 2011; Yeomans et al., 2014), the present study is an anomalous finding compared to otherwise reliable effects.

Given that sensory ratings indicated that the enhanced-sensory preloads were rated as thicker and creamier than the non-enhanced beverages, and that these were rated as more filling it is unlikely that the sensory manipulation was unsuccessful. Indeed the preload formulation was based largely on preloads which have found a robust effect of sensory-enhanced satiety in previous studies (Chambers et al., 2013; Yeomans & Chambers, 2011; Yeomans et al., 2014) and were piloted to ensure that minor formulation adjustments achieved equivalent sensory ratings. The original studies of sensory-enhanced satiety used mixed carbohydrate and protein based formulations (Chambers et al., 2013; Yeomans & Chambers, 2011). There is an argument that these sensory-enhancement effects could be due to a cue for protein content, thus enhancing protein related satiety (Bertenshaw et al., 2013). However more recent studies have



demonstrated similar effects using carbohydrate based preloads (Yeomans et al., 2014). Thus, the present preloads had macronutrient profiles consistent with previous sensory-enhanced satiety effects.

Additionally, the present study measured how “filling” participants thought the preloads were following one taste. This is related to measures of expected satiety explored elsewhere (Brunstrom et al., 2011, 2008; Brunstrom, 2011). These studies demonstrated that people have explicit expectations about the satiety and satiation a particular product is likely to deliver, this may depend on physical characteristics rather than actual caloric content, and may be related to pre-meal planning of intake (Brunstrom, Collingwood, et al., 2010; Fay et al., 2011). Recent research has demonstrated that viscosity is related to expected satiety (Hogenkamp et al., 2011; McCrickerd et al., 2012; Yeomans et al., 2014) and our findings support this given that the enhanced sensory products were rated as more filling following the first taste. One explanation for this could be that people learn that viscosity is a salient cue for satiety from experience with milk feeding (Davidson & Swithers, 2004) with this learned relationship persisting to adulthood. However, in the present study this did not translate into differences in intake or subjective appetite. Additionally this method may not be appropriate for measuring expected satiety - the question itself could have been confusing as to whether the first taste was filling or a specified reference amount to consume later. Future studies should clarify the parameters if measuring expected satiety through VAS.

One limitation of the present study is that the intermediate energy preload conditions did not have equivalent non-enhanced control groups. This meant that the relative satiety enhancement generated by sensory cues compared to the absence of those cues at each energy level was unclear. In the present design the intermediate energy beverages were compared to the low and high energy beverages to assess the extent of satiety generated by these energy additions in enhanced-sensory beverages, and compensation relative to the low energy beverages was compared across preloads. However it is unclear whether compensation would have been weaker or greater in the absence of

sensory-enhancements given that rebound appetite and intake effects have previously been documented (McCrickerd et al., 2014b; Yeomans & Chambers, 2011). Future studies should use energy matched unenhanced control groups at these intermediate energy levels in order to make this comparison.

In conclusion, the present study highlights the idea that the ingestion of covert energy reduces subsequent intake, although in beverages compensation at the next meal is not accurate (see Almiron-Roig et al., 2013). Contrarily to our hypothesis, although providing sensory cues increased post-taste filling ratings, it did not enhance compensation for high-energy preloads. There was tentative evidence that compensation for lower energy, sensory-enhanced beverages was more accurate than high-energy versions. It is still largely unclear however whether the enhanced satiety concept can be used to benefit consumers by providing minimal energy content in beverages with satiety-predicting characteristics. Further studies using energy-matched non-enhanced control groups are needed in order to compare the satiating or rebound effect of sensory cues in intermediate-energy beverages.

## 2.6 Author contributions

The study was designed by PH and MY. PH was responsible for data collection and analysis and manuscript writing, with supervisory input from MY.

### 3 Paper 2: Sensory-enhanced beverages: effects on satiety following repeated consumption at home

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### 3.1 Abstract

Growing research suggests that a consumer's experience of satiety is influenced by information that is present at the time of, or before, food consumption. For example, making small modifications to the sensory characteristics of a high-energy beverage (specifically thickness and creaminess) enhances the impact it has on subsequent satiety. Previous research has examined these sensory-enhanced satiety effects solely in the laboratory and not in the 'real-world'. Therefore, the present study, using a cross-over design, compared the effects of 'real-world' consumption of two high energy versions of a beverage (sensory-enhanced and unenhanced) and a low-energy control beverage on satiety responses. Thirty-four volunteers were provided with shelf-stable dry powder mixes for the three test beverages, which varied in energy content and sensory characteristics, to which they added a commercially available juice. The volunteers prepared and consumed each beverage on eight occasions over a 3-week period in their normal home environment. Controlled satiety testing occurred either side of this exposure period in the laboratory. To further assess consumer acceptability of 'enhanced-satiety' products, two focus groups discussed attitudes towards satiety claims and products. Results of the satiety study indicate that appetite sensations and subsequent food intake were lower following consumption of the sensory-enhanced high-energy beverage relative to the unenhanced and control versions, and that these effects were maintained following repeated consumption of the product in the 'real-world'. The focus groups highlighted that consumers are aware of sensory and cognitive influences on enhancing satiety, though noted that dieting populations might benefit most from satiety-enhanced products. Implications for further research and the role of satiety for consumers and manufacturers are discussed.

### 3.2 Introduction

In the context of a global obesity epidemic (Mozaffarian *et al.* 2015) and public concern over food intake control (Röhr, Lüddecke, Drusch, Müller & Alvensleben 2005) understanding the factors that influence eating motivation is relevant for regulators, product developers and for consumers.

Calorie for calorie nutritionally similar foods are not necessarily equally satiating. Evidence suggests that this is because the satiating power of a food is dependent not only on the physiological post-ingestive effect of its nutrients but also on the consumer's experience of consumption, which can be modulated by a food's sensory characteristics, for example (Cassady, Considine, & Mattes 2012; Chambers, McCrickerd, & Yeomans 2015; Crum, Corbin, Brownell & Salovey 2011; DiMeglio & Mattes 2000; Mattes 1996; Mattes 2005; McCrickerd, Chambers & Yeomans 2014b; Mourao, Bressan, Campbell & Mattes 2007a; Yeomans 2015).

Increasing evidence supports an interactive effect between the sensory characteristics of a beverage and its nutritional content on satiety (Chambers, Ells & Yeomans 2013; Yeomans & Chambers 2011; Yeomans, McCrickerd, Brunstrom & Chambers 2014). Satiety-relevant sensory characteristics of beverages, such as thick texture and creamy flavour, can enhance the satiating capacity of a beverage relative to an equi-caloric beverage devoid of these characteristics (Bertenshaw, Lluch & Yeomans 2013).

However, such an effect is observed only when the product contains sufficient energy; when satiety-relevant sensory characteristics are present in beverages with low energy content subsequent food intake may be increased (Chambers *et al.* 2013; Yeomans & Chambers 2011). One explanation for these effects is that viscosity and creamy flavours predict the delivery of energy resulting in preparatory physiological responses and enhanced detection of nutrients, thus leading to an enhanced satiety response, provided energy was consumed (Yeomans & Chambers 2011). The relationship between food

viscosity and satiety might be learnt early in life during milk feeding with this learning tracking into adulthood (Davidson & Swithers 2004). Furthermore, viscous beverages are associated with longer oral exposure time than non-viscous equivalents, which may promote learning about their nutritional consequences (Mars, Hogenkamp, Gosses, Stafleu & De Graaf 2009) making viscosity a salient cue for satiety (McCrickerd, Chambers, Brunstrom & Yeomans 2012). Indeed, in adults, ratings of viscosity and creaminess are associated with explicit expectations of satiety (Hogenkamp, Stafleu, Mars, Brunstrom & de Graaf 2011; McCrickerd *et al.* 2012; McCrickerd, Chambers & Yeomans 2014) suggesting that consumers can predict how satiating a food will be by assessing its sensory characteristics (*e.g.* Yeomans 2012; Brunstrom 2007). Anticipating the effect a food will have on satiety may have biological utility because it allows for minimal disruption to homeostasis (Woods 1991) and for the selection of foods appropriate for energy needs.

There is evidence that repeatedly consuming a product can change consumer expectations of satiety (Brunstrom, Shakeshaft & Alexander 2010), perhaps because expectations become more accurate with experience (Wilkinson & Brunstrom 2009). A recent study using sensory-enhanced and non-enhanced beverages demonstrated that, at first exposure, consumers' satiety responses depended on both the sensory characteristics and energy content of a beverage, whereas following repeated exposure only the energy-content affected satiety (Yeomans, McCrickerd, Brunstrom & Chambers 2014). This suggests that when a product is novel consumers estimate its satiety value through evaluation of its sensory properties, but, over time, as the product becomes familiar consumers are able to make more accurate predictions about its satiety value based on their actual experiences.

Previous research on sensory enhancements of satiety has taken place in controlled laboratory environments that do not represent 'real-world' conditions where other factors such as distraction (Brunstrom & Mitchell 2006), environmental visual and olfactory appetite cues (Scheibehenne & Wansink 2010; Yeomans 2006) and food

accessibility (Wansink, Painter & Lee 2006) might interfere with learning (Yeomans 2012). This could mean that, on the one hand, sensory enhancements of satiety might be less effective in real-world settings but also that learning about the actual energy content of products may be less robust.

In the present study we assessed whether repeated consumption of a sensory-enhanced beverage in the home environment conferred benefits of improved satiety to the consumer. Satiety responses were assessed in a controlled fashion in the laboratory before and after the home exposure period. Consumers added a commercially available juice to a powder formulation creating beverages differing in energy content and satiety-relevant sensory characteristics. We hypothesised that a sensory-enhanced version of the high-energy beverage would deliver greater satiety than an equi-caloric high-energy beverage without the sensory enhancements. Previous laboratory evidence suggests that sensory effects on satiety may diminish following repeated exposure (Yeomans *et al.* 2014). We expected that outside of the laboratory these learning effects would not be as robust thus allowing sensory effects to persist following repeated exposures. Additionally, we conducted a focus group to examine consumer attitudes to the concept of ‘enhanced-satiety’ and its related claims in order to better understand how these types of products might be received by the consumer.

### 3.3 Method

#### 3.3.1 Design

A repeated-measures design tested the effect of a beverage’s sensory properties and energy content (Table 3.1) on satiety before and after repeated-exposures in the home-environment. Three novel beverages were used: a high-energy high-sensory (HEHS), high-energy low-sensory (HELS), and low-energy high-sensory (LEHS), where ‘high-sensory’ refers to the enhancement of satiety-relevant sensory characteristics (thick texture and creamy flavours). Participants consumed each beverage 10 times in total.

Eight exposures took place in the consumers' ordinary environments and laboratory satiety testing took place before and after these exposures. Satiety responses were examined by measuring energy intake (kcal) of a subsequent test-meal and subjective appetite ratings in the inter-meal interval. Thus, the study was designed to have a naturalistic exposure period in order to assess environmental influences on repeated exposure effects and controlled pre- and post-exposure laboratory testing to accurately examine satiety responses. A 2-week washout period was administered in between the consumption of each of the three beverages. Beverage consumption order was counterbalanced using a Williams Square design. Additionally, consumer analysis of the beverages and attitudes to satiety claims was generated through follow-up focus groups. The focus groups were designed to facilitate broad conversation around a discussion guide (e.g. Parker & Tritter 2006).

### 3.3.2 Participants

Based on a previous study (Yeomans & Chambers 2011) demonstrating an effect size of  $F = 0.25$  for differences in satiety responses to high and low sensory beverages, power analysis suggested an appropriate sample size of  $n = 30$  ( $\alpha = 0.05$ , 95% power). Twelve males and 27 females (in order to account for counterbalancing and predicted attrition) were recruited for a study of 'beverages and satiety' (recent evidence suggests that awareness of satiety testing does not influence intake, e.g. Thomas, Dourish & Higgs 2013). Exclusion criteria were: Dutch Eating Behaviour Questionnaire (Van Strien, Frijters, Bergers & Defares 1986) restraint score  $> 3$ , smokers of  $> 5$  cigarettes per week (e.g. Yeomans & Chambers 2011; Yeomans *et al.* 2014), consumption of  $> 14$  units of alcohol per week, self-reported significant weight-change in the previous 6 months or those on a specific weight change diet, with diagnosed eating disorders, diabetes or gastro-intestinal disorders, those taking prescription medicine, pregnant or lactating women, BMI  $< 18$  or  $> 30$  (actual BMI range = 18 – 30), or age  $< 18$  or  $> 65$  (actual age range = 19 – 61). Volunteers were eligible to participate in the study if their answers to an online screening questionnaire indicated that they did not meet any of the exclusion



criteria. All participants were invited to attend the focus group session one month later. Ten participants (six females) from the original cohort attended the focus group session.

### 3.3.3 Test Beverages

The three test beverages were designed to deliver different combinations of energy content and sensory characteristics (thick texture and creamy flavour). Previous recipes, which have reliably demonstrated sensory-nutrient interaction effects on satiety (Chambers *et al.* 2012; McCrickerd, Chambers & Yeomans 2014; Yeomans & Chambers 2011), were adapted to produce novel shelf-stable powdered mixes that the participants could take home and combine with juice when required (Table 3.1). The dry powder mixes contained maltodextrin (HEHS and HELS), tara gum (HEHS and LEHS), milk caramel flavouring (HEHS and LEHS) vanilla cream flavouring (HEHS and LEHS) and aspartame (LEHS), to which participants added no added sugar mango juice (J. Sainsbury's Inc.). The powdered beverages were presented in transparent 500 ml containers marked with a randomly generated three digit code used for identification of the beverage type by the experimenters. A marker on the side of the container indicated the correct amount of juice to add.

### 3.3.4 Preparation of test beverages

Participants were provided with containers of the dry powder mixes and sufficient juice to prepare eight beverages at home. Ingredients were dispensed to participants following pre-exposure laboratory satiety test sessions. Participants were instructed to pour juice into the containers, up to a marker denoting the correct amount on each container, then shake the container in order to disperse the powder and refrigerate until consumption the following day. The beverages were consumed mid-morning on Mondays, Wednesdays and Fridays at least one hour following and prior to consumption of other foods or caloric beverages (exact time not specified). A calendar was provided to ensure adherence to the schedule and for recording deviations. For the

laboratory satiety testing (before and after home-exposures) the beverages were prepared by the experimenters, in an identical manner as instructed to participants.

*Table 3.1 Test beverage ingredients and macronutrient composition*

Ingredients (g)	LEHS	HELS	HEHS
No added sugar mango juice <sup>a</sup>	317	265	262
Maltodextrin <sup>b</sup>	0	55	55
Aspartame <sup>c</sup>	0.03	0	0
Tara gum <sup>d</sup>	1.0	0	1.0
Milk caramel <sup>e</sup>	0.8	0	0.8
Vanilla cream <sup>e</sup>	1.0	0	1.0
Total (g)	320	320	320
Total carbohydrates	30.8	79.9	78.0
Total protein	1.6	1.3	1.3
Total fat	0	0	0
Total kcal	41.2	243.3	243.2

<sup>a</sup> J. Sainsburys, Inc, UK; <sup>b</sup> Cargill, UK.; <sup>c</sup> Aspartame Powder, Ajinomoto Sweeteners Europe; <sup>d</sup> Kaly's Gastronomie, FR; <sup>e</sup> TH Geyer, DE.

### 3.3.5 Laboratory Satiety Measurement

An *ad libitum* test-meal was administered one hour after consumption of the test beverage. The test-meal contained 620 g (cooked weight) of penne pasta (J. Sainsbury's plc.) with 650 g of Dolmio tomato original bolognese pasta sauce (Mars Inc.) plus 30 g vegetable oil (J. Sainsbury's plc.) and 100 g medium cheddar cheese (J. Sainsbury's plc.). Per gram, the test-meal delivered 1.53 kcal, 0.5 g carbohydrate, 0.1 g protein and 0.1 g fat. The meal was pre-prepared by boiling the pasta and adding the remaining ingredients before refrigerating. The meal was baked for 30 minutes at 175 degrees Celsius before consumption. The meal was served in an aluminium tray and participants were provided with 150 ml of drinking water.

Participants' appetite, appetite expectations, and sensory evaluations of the test beverages and test-meal were measured using 100 point visual analogue scales (VAS) presented using a hand-held computer [iPad mini, Apple Inc.: see Brunger *et al.* (2014)]. These were operated by dragging a pointer across a horizontal line using the computer's touch-screen. Appetite ratings of hungry, full and thirsty, and appetite expectations ratings of hungry and full immediately and one hour later, were administered in the format: 'how <rating> are you/ would you expect to be immediately/one hour after consuming the beverage?' anchored by: 'not at all' and 'extremely'. Additionally, prospective consumption was measured in the format: 'how much do you think you could eat right now?' using anchors: 'nothing at all' and 'a very large amount', and desire to eat was measured in the format: 'how strong is your desire to eat?' anchored by 'very weak' and 'very strong' (e.g. Hill, Magson & Blundell 1984).

All three beverages were rated for familiarity, pleasantness, thickness and creaminess to check that they differed in the intended dimensions (thickness and creaminess) and were similar in other sensory dimensions (familiarity and pleasantness). Additionally, participants rated the familiarity and pleasantness of the pasta test-meal on all satiety test days. Ratings followed the format: 'how <rating> is the beverage/ pasta?' anchored by: 'not at all' and 'extremely'.

### 3.3.6 Procedure

On all satiety testing days, participants were instructed to fast from 20.00 the evening before; consume the same meal on all evenings prior to test sessions; avoid significant dietary changes; avoid strenuous exercise and alcohol for 24 hours prior to test session; and use the same mode of transport to attend the laboratory for each test session. Self-reported compliance with these procedures was checked.

On satiety test days, participants consumed a standardised breakfast at 09.00 in individual concealed booths (as were all meals and test beverages). Following breakfast, they returned to the laboratory waiting room where 150 ml of water was provided at 10.00 and 11.00. At 12.00 iPad Mini computers were given to participants. As well as being the method for collecting ratings, the iPads provided timed instructions that lead the participant through the experimental procedure. Baseline appetite ratings were then completed before they consumed the relevant test beverage in the concealed booths. One mouthful of the beverage was consumed and sensory and appetite-expectation ratings were completed. Participants then consumed the remaining beverage and completed further appetite ratings.

Thirty minutes after consumption of the beverage further appetite ratings were measured. After a further 30 minutes, pre-meal appetite ratings were completed. Participants then returned to the testing booths where the *ad libitum* test-meal was provided with a 150 ml cup of drinking water. One mouthful of the test-meal was consumed and appetite and sensory ratings were completed. Next, participants were instructed to consume the test-meal until comfortably full, such that the extent of satiety generated by the beverage could be measured. Final appetite ratings were administered when consumption ceased (see Figure 3.1 for laboratory test day schematic).

Each satiety test session followed an identical procedure. Participants were then provided with the beverage ingredients and instructions to prepare and consume the beverage eight times (three times per week and twice in the last week) as a mid-morning snack. A 2-week washout period was observed between beverage condition phases. Ethical approval to run the study was obtained from Reading Independent Ethics Committee.



*Figure 3.1 Procedure timeline for satiety testing*

### 3.3.7 Focus Group

One month following the main study two focus groups were conducted to explore consumer attitudes to satiety claims and enhanced satiety products. All participants from the main study were invited to take part (participants remained naïve about the aims of the study and the manipulations). Ten participants were recruited. The group followed a discussion guide agreed by the researchers (see below), which broadly covered issues relating to consumer understanding and acceptability of satiety claims and manipulation of products to promote satiety, and allowed free discussion on the topic [see focus group method discussion in Parker & Tritter (2006)]. One experimenter guided discussion, which was video-recorded for analysis; all participants consented to the video recording. Broad themes relating to consumer experiences of enhanced satiety were identified from discussion around these structured topics for analysis. Data saturation was not achieved.

### 3.3.8 Discussion Guide:

#### *Consumers General Trends*

First, general trends in familiar product claims were discussed. The topics discussed were which claims and products come to mind, and whether participants had ever purchased one. Following this, an energy drink, a smoothie, a yoghurt drink, a carbonated beverage, a fruit juice and a bottle of water were presented and participants were prompted to discuss the relative purpose of each product, claims associated with it and whether it was likely to promote satiety.

#### *Appetite Claims*

Some specific claims: ‘reduces hunger’, ‘increased fullness’, ‘helps you eat less at your next meal’ were discussed in terms of how easy they were to understand, whether consumers would like to experience the state that the claims promoted, what type of products suited each claim, and whether any would be appropriate for a beverage. Participants were then asked the factors they consider when thinking about how full they would feel following consumption and whether sensory factors played a role in this state.

#### *Sensory Characteristics of Enhanced-Satiety Beverages*

The discussion then focused on whether sensory enhancements of beverages to promote satiety would be desirable. The claims ‘optimised texture’, ‘enhanced sensory properties’, ‘thickened’ and ‘added tara gum’ were discussed in terms of their acceptability, ease of understanding, and what type of products would be associated with such claims. Participants were also prompted to discuss the merits of beverages in the promotion of satiety and whether they could be regarded as a ‘snack’.

### *Experience of Diet Products*

Participants then discussed diet products and the characteristics that determine an effective diet product. The idea of ‘making the most of your calories’ was also discussed in term of how to maximise the satiety experienced from consuming a certain energy load. Finally, participants discussed whether they believed that claims regarding satiety would be relevant for consumers in the future.

#### 3.3.9 Data Analysis

Intake was analysed using three (beverage: HEHS, HELS, LEHS) by two (exposure: pre-exposure, post-exposure) repeated measures analysis of variance (ANOVA). One-tailed  $p$  values were used, given the hypothesis that test-meal intake would be lower following consumption of the HEHS beverage compared to the HELS and LEHS beverages, and that intake would be lower in the HELS than the LEHS condition. Additionally, gender was included as a factor, and BMI and dietary restraint score (DEBQ) were entered as covariates and are reported where significant.

Appetite ratings were analysed using three-way three (beverage condition) by two (exposure) by five (rating time: baseline, post-beverage, 30 minutes post-beverage, pre-test-meal, post-taste of test-meal) repeated measures ANOVAs. Planned contrasts were used to further explore differences between beverage conditions. A composite satiety score was generated by reversing hunger, desire to eat and prospective consumption ratings and averaging these along with fullness ratings (*e.g.* Brunger *et al.* 2014). All error bars presented were corrected for repeated-measures variance.

### 3.4 Results

Five participants failed to complete the study and their data were excluded. The following analyses were conducted with  $n = 34$ . Participants’ mean age was 43.4 years

(SEM = 2.0), with a mean BMI of 24.0 (SEM = 0.4) and a mean DEBQ restraint score of 2.1 (SEM = 0.1).

#### 3.4.1 Test-meal intake

Figure 3.2 suggests that *ad libitum* intake of the test-meal was lower following the HEHS beverage than the HELS and LEHS versions respectively, and that intake was higher following repeated exposure to the beverages in all conditions. This was confirmed by the analyses: there were significant main effects of beverage [ $F(2, 66) = 10.85, p < .001, \eta^2_p = .24$ ] and exposure [ $F(1, 33) = 8.09, p = .008, \eta^2_p = .20$ ] but no interaction [ $F(2, 66) = 0.85, p = .43, \eta^2_p = .03$ ]. Overall, test-meal intake following the HEHS beverage was significantly lower than following the HELS version [ $p = .043$  (one-tailed)]. Intake was significantly lower following the HEHS than LEHS [ $p < .001$  (one-tailed)] and following the HELS than the LEHS [ $p = .005$  (one-tailed)]. This suggests that the HEHS beverage was the most satiating and that this effect persisted followed repeated exposure. Potential effects of BMI, restraint score and beverage order were not significant. There was a significant effect of gender [ $F(1, 32) = 11.24, p = .002, \eta^2_p = .26$ ] with men eating more than women, as expected, but there were no interactions between gender and beverage condition or exposure (all  $p > .05$ ). The test-meal did not differ in pleasantness between beverage conditions [ $F(2, 66) = 0.83, p = .439, \eta^2_p = .03$ ] or exposures [ $F(1, 33) = 0.27, p = .61, \eta^2_p = .01$ ].



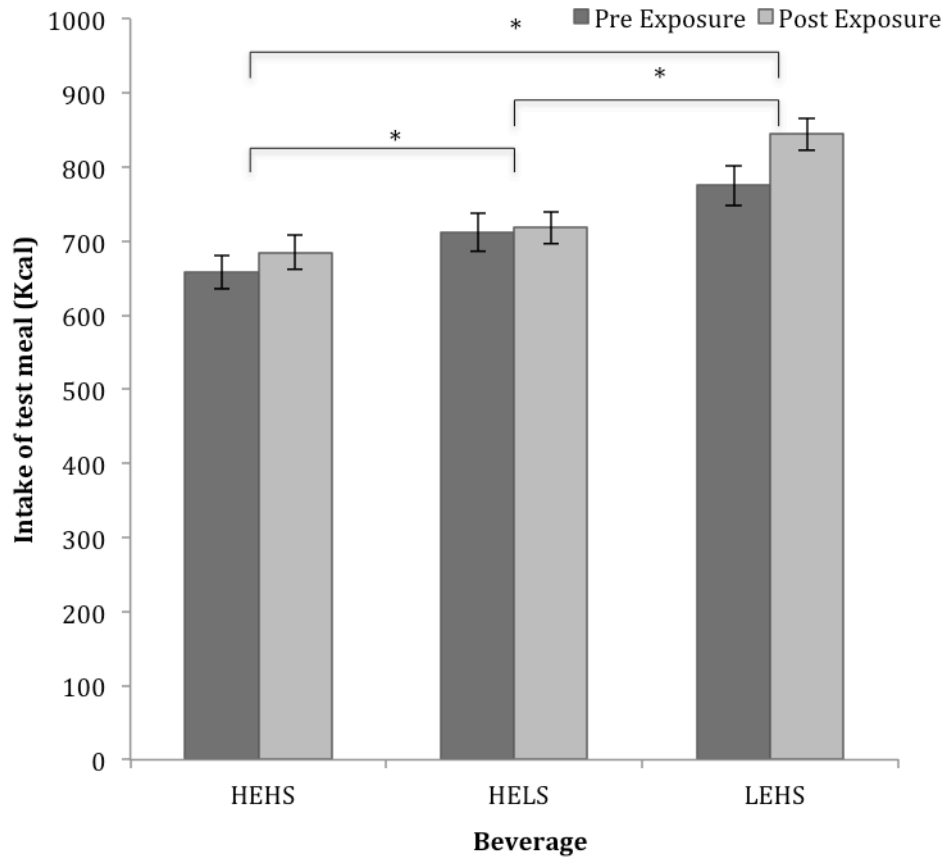


Figure 3.2 Ad Libitum energy intake (kcal) following the three test beverages pre- (dark grey bars) and post-repeated exposures (light grey bars). Data are mean  $\pm$  SEM. \*significant difference between all beverage conditions and main effect of exposure time ( $p < .05$ ).

### 3.4.2 Rated appetite

Figure 3.3 shows participants' appetite throughout the test day. In summary, hunger was lower and satiety greater following the HEHS beverage, and this pattern persisted following exposure. There was a significant main effect of beverage on hunger [ $F(2, 66) = 2.81, p = .034, \eta^2_p = .08$  (one-tailed)], which was lower following the HEHS beverage than following the HELS [ $p = .022$  (one-tailed)] and the LEHS versions [ $p = .032$  (one-tailed)]. A significant main effect of exposure [ $F(1, 33) = 5.00, p = .032, \eta^2_p = .13$ ] indicated overall lower hunger at pre-exposure compared to post-exposure. However, there was no interaction between beverage condition and exposure ( $p > .05$ ).

There was also a significant main effect of beverage on fullness [ $F(2, 66) = 3.1, p = .026, \eta^2_p = .09$  (one-tailed)] and desire to eat [ $F(2, 66) = 2.68, p = .038, \eta^2_p = .08$  (one-tailed)], which tended to be lower in the HEHS condition compared with the HELS condition ( $p = .067$ ) and the LEHS condition ( $p = .058$ ). There were significant main effects of beverage condition on prospective consumption [ $F(2, 66) = 2.94, p = .03, \eta^2_p = .08$  (one-tailed)], which was significantly lower following the HEHS beverage than the HELS ( $p = .022$ ), and LEHS ( $p = .025$ ) versions. Likewise, there was a significant main effect for composite satiety score [ $F(2, 66) = 3.13, p = .025, \eta^2_p = .09$  (one-tailed)], which was greater in the HEHS condition than the HELS [ $p = .056$  (one-tailed)] and the LEHS conditions [ $p = .017$  (one-tailed)].

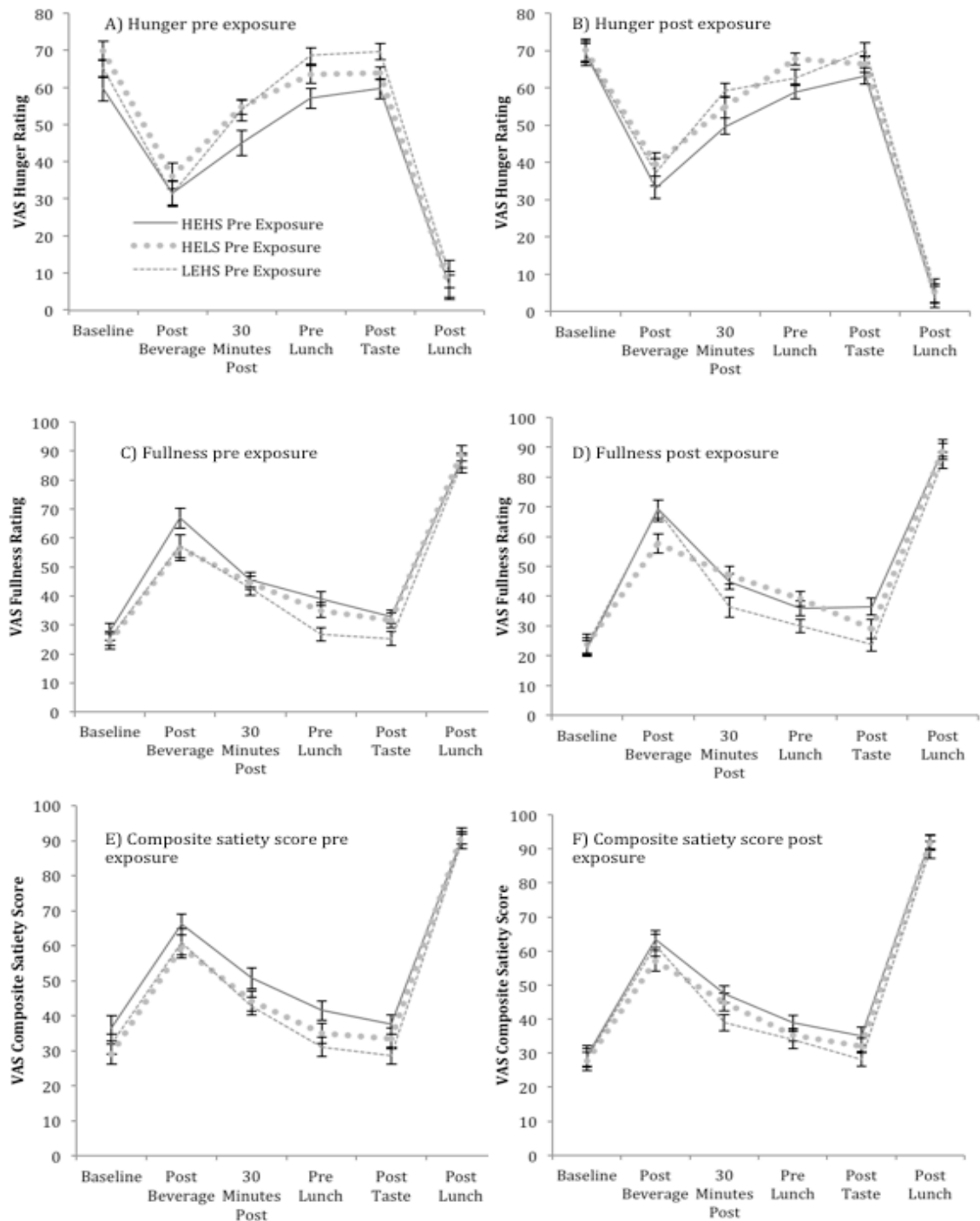


Figure 3.3 VAS ratings of hunger (A and B) and fullness (C and D), and composite satiety ratings (Figures E and F), before and after repeated exposures to each beverage. Solid line represents HEHS, dots represent HELS and dashes represent LEHS. Data are mean  $\pm$  SEM.

### 3.4.3 Laboratory Measured Expected Satiety

Unexpectedly there were no significant effects of beverage condition or exposure on appetite expectations either immediately or one hour after beverage consumption (all  $p > .05$ , means in Table 3.2). This is inconsistent with our hypothesis, as satiety-relevant sensory characteristics of beverages are thought to increase expected satiety. Moreover, evidence suggests that expected satiety becomes more aligned to the actual energy content of a product following repeated exposure (Wilkinson & Brunstrom 2009) and thus we predicted that post-exposure expected satiety would increase for the high-energy versions of the beverages. The present data do not support this hypothesis.

*Table 3.2 Mean (SEM) VAS ratings of appetite expectations across beverage condition and exposure times*

	HEHS		HELS		LEHS	
	Pre-exposure	Post-exposure	Pre-exposure	Post-exposure	Pre-exposure	Post-exposure
Expected hunger immediate	40.3 (4.1)	34.9 (3.3)	35.2 (3.7)	41.7 (3.5)	33.4 (3.9)	42.1 (3.6)
Expected hunger later	48.4 (4.0)	46.8 (3.0)	47.7 (3.4)	55.1 (3.1)	49.9 (3.2)	49.9 (3.2)
Expected fullness immediate	62.1 (3.5)	63.2 (3.5)	60.0 (3.2)	56.9 (2.8)	60.5 (3.5)	65.2 (2.8)
Expected fullness later	52.6 (3.8)	54.7 (2.7)	48.5 (2.6)	48.5 (3.6)	51.2 (3.0)	47.0 (3.7)

### 3.4.4 Beverage characteristics

Table 3.3 indicates that the beverages differed in key domains (thickness and creaminess) confirming that the sensory manipulations were successful. This was confirmed by a significant main effect of beverage condition on thickness ratings [ $F(2, 66) = 33.45, p < .001, \eta^2_p = .50$ ] but no main effect of exposure [ $F(1, 33) = 1.72, p = .199, \eta^2_p = .05$ ]. The HEHS beverage was rated as thicker than the HELS ( $p < .001$ ) but not different from the LEHS ( $p = .14$ ) and the LEHS was rated as thicker than the HELS ( $p < .001$ ). There was a main effect of beverage condition on rated creaminess [ $F(2, 66) = 6.974, p = .002, \eta^2_p = .17$ ] but no effect of exposure [ $F(1, 33) = 2.88, p = .099, \eta^2_p = .08$ ]. The HEHS and LEHS beverages were rated creamier than HELS version ( $p = .001$  and  $p = .057$  respectively) and the HEHS and LEHS versions did not differ ( $p = .751$ ). For pleasantness ratings, there was a significant main effect of beverage condition [ $F(2, 66) = 3.479, p = .037, \eta^2_p = .10$ ] but not exposure [ $F(1, 33) = 1.72, p = .199, \eta^2_p = .05$ ]. The HEHS beverage was rated as less pleasant than the HELS version ( $p = .04$ ) but there was no difference between the HEHS and the LEHS ( $p > .999$ ) versions or the HELS and the LEHS versions ( $p = .175$ ).

*Table 3.3 Mean (SEM) VAS ratings of beverage characteristics*

	HEHS		HELS		LEHS	
	Pre - exposure	Post- exposure	Pre- exposure	Post- exposure	Pre- exposure	Post- exposure
Thick	72.5 (1.8)	71.2 (2.0)	44.7 (3.5)	55.0 (1.9)	66.7 (1.8)	65.0 (2.4)
Creamy	51.1 (2.9)	54.9 (3.2)	38.9 (3.5)	41.7 (2.7)	45.2 (2.6)	52.0 (2.7)
Pleasant	62.1 (2.0)	60.0 (2.1)	68.7 (2.4)	66.2 (2.1)	64.0 (2.7)	61.1 (2.0)
Familiar	56.2 (4.8)	78.9 (3.5)	66.9 (3.3)	77.8 (2.8)	56.4 (4.3)	79.4 (3.2)

### 3.4.5 Focus Group

The key themes emerging from discussion around the topics presented in the discussion guide are reported below.

#### 3.4.5.1 Appetite Claims

A commercially available yoghurt-based beverage, smoothie, carbonated beverages and fruit juice were presented. The yoghurt-based beverage was regarded as the most likely to be filling because it was ‘more of a food than a drink’ although ‘it wouldn’t be thirst-quenching’. Consumers indicated that if they ‘had to skip breakfast’ the smoothie or the yoghurt beverage would be most appropriate replacement because of the ‘thickness’, because they ‘were more like food...because of the fruit’ and because ‘(they have) more bulk’. Participants then discussed the claims ‘reduced hunger’, ‘increased fullness’ and ‘helps you eat less at your next meal’. The latter was unanimously noted to be the most difficult to understand. Some participants claimed that it ‘(did not) make sense’ because ‘the next meal would be too far away’ and that such a product would not be calorific and would be consumed immediately before the meal. Participants suggested that this claim would be appealing to those wishing to lose weight. In terms of ‘reducing hunger’ some participants were suspicious of the claim because ‘it would have to be artificial (in order to) trick the body’ and that ‘reduced is a negative term’. Other participants claimed that they would like to experience reduced hunger ‘if you know there will be a gap between meals’. Increased fullness was regarded as unacceptable as it ‘sounds like bloating’ and the word ‘filling’ was suggested as a more appropriate term. Both groups commented that ‘substance’ and ‘thickness’ were important characteristics of beverages with ‘reduced hunger’ and ‘increased fullness’ claims and that yoghurt-based beverages would suit such claims because ‘they’re made from food’ and that ‘(thickness) makes a drink more of a snack’. Participants also noted dynamic effects: ‘(carbonated beverages) would fill you up immediately but it would wear off in half an hour’.

#### 3.4.5.2 Sensory Characteristics of Enhanced Satiety Beverages

Caloric content was not regarded as important a characteristic as texture for ‘filling’ beverages. Considering two hypothetical products that were equally calorific but one which was more filling “(participants’) first thought would be ‘what’s in it?’”. Specifically, exploring the idea of thickening a beverage to achieve this ‘enhanced-satiety’ effect, reaction was mixed as some participants were concerned about ‘associations with artificial thickener’ because it would ‘not be as pleasant’ if thickened, although others were generally receptive. Four more claims were discussed: ‘optimised texture’, ‘enhanced sensory properties’, ‘thickened’, and ‘added tara gum’. Both groups agreed that ‘thickened’ was the easiest claim to understand, although one participant was concerned about: ‘thickened with what?’ and suggested that ‘thicker’ was more acceptable than ‘thickened’ due to associations with artificial additives. ‘Optimised texture’ and ‘enhanced sensory properties’ were regarded as ambiguous. ‘Added tara gum’ was easy to understand although treated with suspicion as tara gum was an unfamiliar ingredient and ‘added...sounds synthetic’. One participant suggested that ‘with’ would be a more acceptable term than ‘added’. Participants suggested that beverages could ‘help to manage appetite...but not as much as food’ and some considered beverages to be ‘equivalent to a snack’. Both groups suggested that ‘milky drinks’ or ‘milk-based drinks’ could help to manage appetite ‘because they contain protein’ and ‘thickness’ was ‘a tipping point between a drink and a snack’. Regarding smoothies, participants suggested that healthy snacks could be filling but ‘it depends on the portion size’.

#### 3.4.5.3 Experience with Diet Products

Participants were asked about whether ‘making the most out of calories’ was important. The reaction was mixed with some participants reacting positively, particularly as they would use a filling product in a ‘modern lifestyle’ in which meals are arranged around busy schedules. Other participants suggested that it would be more useful for weight

loss than everyday use and that it would be ‘more of a bonus than something driving purchasing’. Some suggested that feeling full was ‘not important to people’, although healthy snacking is ‘something for the future’ and ‘people want to buy into it’.

### 3.5 Discussion

The study hypothesis that satiety responses to a high-energy beverage would be enhanced by the addition of satiety-relevant sensory characteristics is supported by the present findings. Additionally, we hypothesised that repeated exposures to the beverage in consumers’ natural environments would lead to less robust learning and thus less of a diminished response to the sensory enhancements than observed in laboratory-based learning studies (*e.g.* Yeomans *et al.* 2014). Whilst repeated exposure to the beverages appeared to decrease satiety responses overall, the sensory enhanced high-energy beverage continued to generate the greatest satiety. This suggests that in naturalistic environments a product’s sensory cues remain important for satiety even when the product is repeatedly consumed. This pattern was observed both in terms of subsequent energy intake and rated subjective appetite.

The present findings differ to previous research, which investigated sensory-nutrient interactions following repeated exposures in a laboratory (Yeomans *et al.* 2014). This study found that whilst sensory manipulations enhanced satiety before repeated exposures, satiety was dictated by energy content alone following repeated exposures. Yeomans and colleagues’ results suggest that learning about the energy content of the beverages over repeated exposures resulted in a change in satiety responses consistent with the energy consumed. No such interaction was observed in the present study. Instead, while satiety responses decreased overall following repeat exposures, the superior satiating effect of the enhanced sensory high-energy beverage was maintained. The differences between these findings may be due to contextual influences during the exposure period. The laboratory presents a controlled environment in which attention to the test product is emphasised. Distraction during consumption of a test product has



been shown to reduce satiety by modulating the influence of pre-absorptive satiety-relevant signals (Brunstrom & Mitchell 2006). It is plausible, therefore, that uncontrolled influences in the consumers' environments diminished the attention paid to consuming the beverages during the exposure phases, thus modulating learning about the satiety value of the beverages. If this is the case, this study highlights the differential response that may be obtained in a laboratory and outside of it, with important implications for behavioural science. Indeed, other studies that examined food-based learning effects in the real world have failed to find an effect (Mela, Trunck & Aaron 1993). The literature regarding learned influences on appetite and food preferences presents a complex picture of the conditions that allow learning effects to be realised (Mela 1999; Yeomans 2012). Given the relatively uncontrolled conditions beyond the laboratory, it is plausible that learning in the 'real-world' is less robust than within the laboratory. Thus, for research findings to be applied to consumer contexts situational variables must be considered; this means that consumer-focused studies may be required in addition to experimental research, particular for substantiation of a health claim. For manufactures, these findings imply that sensory-enhanced products may be effective at enhancing satiety when consumed repeatedly in real-world environments, but also, more generally, that long-term effects of products observed in the laboratory may not be instantly generalizable to the consumer environment.

The present study gathered qualitative data regarding consumer awareness and attitudes towards enhanced satiety products. The focus groups indicate that a product with thick sensory properties would be a desirable characteristic with regards to enhancing satiety, as would characteristics that frame the product more as a food than a beverage, such as 'bulk' and 'substance'. Food form (Kissileff 1985; Mourao, Bressan, Campbell & Mattes 2007b) as well as beliefs about the purpose of the food are known to influence satiety (Crum *et al.* 2011; McCrickerd *et al.* 2014b) suggesting that cognitions generated by information about products can modulate later food consumption and appetite. Participants in the current study regarded a product's sensory characteristics more important than its caloric content for the delivery of 'enhanced satiety'. These

observations support our quantitative data, showing that external satiety cues influence actual satiety responses. Importantly, these qualitative findings demonstrate that consumers are influenced by external satiety cues both within and outside of an eating episode. This has important implications for food manufacturers as product modifications, such as the subtle sensory enhancements tested in the present study, may offer appetite-related benefits for consumers concerned with satiety.

In the present study, whilst there were clear effects of the beverage's sensory characteristics on the participants' experienced satiety this was not reflected by reports of their expectations of satiety. Previously, ratings of expectations of satiety have been shown to either increase with familiarity (Brunstrom, Shakeshaft *et al.* 2010) or become more aligned with actual satiety (Wilkinson & Brunstrom 2009). We found no evidence that satiety expectations differed from pre- to post-repeated exposures with any of the products, despite differential satiety responses. This suggests that either explicit reports of increased expected satiety are not a prerequisite for sensory-enhanced satiety or that self-reports of this measure are not adequately sensitive to capture small shifts in participants' beliefs.

The sensory ratings suggest that the sensory manipulations were successful in terms of generating increased thickness and creaminess in the enhanced-sensory versions of the beverage. However, ratings of creaminess were relatively low in all of the beverages. This might mean that the perceived thickness of the beverages is the main driver of the sensory-enhanced satiety effect. This is consistent with previous findings that found that thickening beverages reduced intake whereas adding creamy flavours had no additional effect (McCrickerd *et al.* 2014). Thickness might be a particularly salient satiety cue because the viscosity of breast-milk is directly related to its energy density (Davidson & Swithers 2004), indicating that a learned predictive relationship between this characteristic and satiety is established early in life.

The present data indicate that whilst satiety-enhancing beverages are effective when prepared by consumers and consumed repeatedly in a naturalistic way, the effects on satiety are subtle. Overall there was a mean test-meal intake difference between the sensory enhanced and unenhanced high energy beverages of 43.9 kcal, representing 1.8% of men's and 2.2% of women's daily intake guidelines (NHS Choices 2015) respectively. But whilst subtle, these effects are robust. The satiety ratings generated small standard errors and the data are consistent with previous accounts regarding the sensory enhancement of satiety (Bertenshaw *et al.* 2013; Chambers *et al.* 2013; Yeomans & Chambers 2011; Yeomans *et al.* 2014). Another limitation is that the HEHS beverage was rated as slightly less pleasant than the other versions. This is a concern because there is some suggestion that palatability of a preceding food, beverage or meal is positively related to desire to eat and hunger for two hours following consumption (Hill *et al.* 1984), in which case the relatively reduced appetite ratings following the HEHS beverage may be because participants found it less palatable. On the other hand, there is some debate as to whether food palatability can affect consumption at a later test-meal (Sørensen, Møller, Flint, Martens & Raben 2003).

The focus group data in the present study suggest that consumers perceive that those most interested in weight loss would benefit most from enhanced satiety products. It is therefore important to consider that dieting and highly restrained populations tend to be more responsive to external satiety cues and less to internal cues relative to unrestrained individuals (Ogden & Wardle 1990) and to date the sensory-nutrient interaction literature has focused on unrestrained participants (*e.g.* Chambers *et al.* 2012; Yeomans & Chambers 2011). Thus, our focus group data urges research into restrained populations in order to assess whether they would benefit from sensory-enhanced products.

In conclusion, this study provides further evidence that a sensory-enhanced high-energy beverage is more satiating than the same high-energy beverage without the sensory enhancements, and provides new evidence that this satiety benefit is maintained

following repeated consumption of the product in the ‘real-world’. Furthermore, this study provides information on consumers’ perspectives of ‘enhanced satiety’ and indicates that they are receptive to products that deliver this benefit. The results of this ‘real-world’ study differed slightly to those generated in the laboratory demonstrating the need to explore research findings in consumer-relevant environments, if the intention is to extrapolate findings to appetite management products.

### 3.6 Acknowledgements

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## 4 Paper 3: The effect of dietary restraint and disinhibition on sensory-enhanced satiety

### 4.1 Abstract

Recent research has demonstrated that by providing satiety-relevant sensory cues (viscosity and creamy flavours) in beverages satiety can be enhanced. However these effects interact with the energy content of the beverage such that insufficient energy delivery can lead to greater hunger. These studies offer valuable insight into potentially useful high-satiety product design concepts. However to date this research has not considered the role of dietary restraint status – an omission which limits the ability to generalise the findings to consumers, particularly given that highly-restrained consumers are likely to be a key market for such products. The present study explored sensory-nutrient interactions using a classic preload technique, and compared subjective and behavioural satiety measures between individuals varying in restraint status (pre-measured using the TFEQ). The results suggested that highly restrained participants with a propensity for disinhibition compensated more accurately for the energy in non-enhanced beverages (a finding contrary to those from previous research using non-restrained individuals). Meanwhile differences between the enhanced and unenhanced preloads with restrained individuals with low disinhibition scores, and those scoring low in both, did not reach significance. There were no meaningful effects on subjective appetite ratings. Overall these findings suggest that sensory-enhanced satiety might not benefit highly restrained consumers with a propensity to disinhibit. Whilst the findings from both low disinhibited groups were unclear this was likely due to power issues.

## 4.2 Introduction

Foods which have been optimised to generate satiety have been identified as potentially beneficial to consumers due to their utility in maintaining dietary goals and reducing hunger-related dysphoria (Hetherington et al., 2013). However, in order to understand whether these benefits can truly be realised, satiety studies which assess whether the apparent enhancement of satiety seen in laboratory based studies are also evident in consumer-relevant contexts, using representative study populations (Meiselman, 1992a). Following from a previous study which assessed whether satiety enhancements persist over repeated exposures to the test products in home-consumer contexts (Hovard et al., 2015), the present study attempted to address enhanced satiety in a consumer-relevant population.

The enhanced satiety concept is rooted in the presently accepted theory that appetite control is a multi-faceted construct involving metabolic, sensory and cognitive signals (e.g. Berthoud, 2006, 2012; Blundell, 1991; Blundell et al., 2010; Blundell, Green, & Burley, 1994; Blundell, Lawton, Cotton, & Macdiarmid, 1996). According to this conceptualisation homeostatic control of energy requirements is modulated by sensory mechanisms, cognitive processes and representations of food stimuli (Berthoud, 2012). Indeed studies which introduce energy loads at various stages of the gastro-intestinal tract have found that satiety is greatest when a combination of cognitive, oral and gastric feedback is possible (Cecil et al., 1998; S J. French & Cecil, 2001). The influence of cognitive and sensory factors in satiety has been demonstrated by numerous studies which report greater satiety for foods presented as filling (Capaldi et al., 2006; Crum et al., 2011; McCrickerd et al., 2014b; Pliner & Zec, 2007; Wooley, 1972), and lower satiety associated with liquid preloads (Almiron-Roig et al., 2013; DiMeglio & Mattes, 2000; Flood-Obbagy & Rolls, 2009; Hulshof et al., 1993; Mattes, 1996; Mourao et al., 2007), particularly those that are low in viscosity (Bertenshaw et al., 2013; Mattes & Rothacker, 2001; Zijlstra et al., 2010; Zijlstra, Mars, et al., 2009). Meanwhile, despite their liquid form, soups tend to deliver relatively high satiety

(Mattes, 2005), and beliefs about the physical state of ingested foods can influence the physiological and subjective reaction, where foods believed to become liquid in the stomach generated weaker satiety (Cassady et al., 2012). These pre-ingestive influences on satiety likely involve cephalic phase responses (CPRs) – learned physiological responses generated by food cues (such as the sight, smell, taste and even thought of food) which enhance the efficiency of digestive processes, and consequently, satiety responses (Power & Schulkin, 2008; Smeets et al., 2010; Woods, 1991). Liquids are associated with shorter oral-exposure time than solids, more viscous liquids, or liquids consumed more slowly (for example soups consumed with a spoon). Therefore the pre-ingestive feedback that non-viscous liquids generates may be weaker, hence limiting their satiating capacity (de Graaf, 2012). Additionally given that the relationship between viscosity and energy delivery may be learned early in life through exposure to breast-milk (Picciano, 1998) viscosity may be an important learned cue for energy delivery. Together, these findings suggest that beliefs about foods and their sensory characteristics can influence the satiety that they deliver by modulating nutritionally-relevant feedback.

Accordingly, a recent series of studies examined the extent to which cognitive and sensory cues interact with nutritional factors to determine satiety. In the first of these studies participants consumed liquid preloads with and without additional covertly added 200kcal energy loads, and with and without satiety-relevant sensory cues (viscosity and creamy flavours: Yeomans & Chambers, 2011). The findings suggested that participants compensated more accurately for covert energy additions, and reported higher satiety, when the beverages were consumed in the enhanced-sensory context. However when the beverages were enhanced with viscosity and creamy flavours, but *without* the 200 kcal energy addition higher hunger ratings were reported. The authors explained this rebound effect as a consequence of mismatching between the satiety cues and energy delivery which caused the body to prepare for energy which did not arrive (see Chambers, McCrickerd, & Yeomans, 2015). These findings have been supported by studies which also found no additional effects of satiety-relevant labelling

(Chambers et al., 2013) and a greater effect of sensory cues than framing the preload as filling through pre-ingestive explicit information (McCrickerd et al., 2014b). Additionally a follow-up study found that when consumed over repeated exposures initial enhanced satiety effects diminished, with the energy content dictating satiety responses following the exposure period (Yeomans et al., 2014). These studies suggest that satiety-relevant characteristics interact with the nutritional content and learning processes to determine satiety responses.

These findings have clear potential utility for consumers, and offer insight into the development of diet products. Yeomans has noted that a common strategy for manufacturing diet products is to aim to match the sensory profile of low-energy products to their high-energy equivalents in order to maintain product acceptance (Yeomans, 2015). This strategy is clearly counter-productive given the risks of rebound hunger and the necessity of sensory cues and energy delivery for generating satiety (Yeomans & Chambers, 2011). Thus this sensory-enhanced satiety literature has potentially important implications for consumers. A recent study aimed to explore the concept in a consumer-relevant manner by administering repeated exposures to the beverages in a home-consumer trial, with controlled satiety testing before and after the exposure period (Hovard et al., 2015). The results suggested that satiety was enhanced before and after repeated exposures by enhanced sensory characteristics, suggesting that the concept could have utility for real consumers outside of the laboratory. Additionally, focus groups suggested that diet-conscious, and time-limited, consumers would be particular beneficiaries of the enhanced satiety concept (Hovard et al., 2015). This finding is significant given that the enhanced satiety literature to date has screened for, and excluded, individuals reporting high dietary restraint, thus limiting the real-world application of the findings (Chambers et al., 2013; Hovard et al., 2015; McCrickerd et al., 2014b; Yeomans & Chambers, 2011; Yeomans et al., 2014).

Dietary restraint refers to the attempts of individuals to restrict their intake (Herman & Mack, 1975; Herman & Polivy, 1983), and is quantified by responses to questionnaires



such as the three factor eating questionnaire restraint scale (TFEQ-R). The TFEQ also measures the extent to which individuals are likely to be subject to disinhibition of restraint (TFEQ-D; Stunkard & Messick, 1985). Some individuals (identified by high scores on TFEQ restraint and disinhibition scales) attempt to restrict their intake but overeat when that restraint is disinhibited by breaking a perceived diet boundary, through forced consumption of a preload (Westenhoefer et al., 1994), or other stimuli which reduce the capacity for restraint such as dysphoric moods (Haynes et al., 2003; Yeomans & Coughlan, 2009). Meanwhile other studies have found that those reporting high restraint and disinhibition (but not those reporting low tendency to disinhibit) overeat palatable foods relative to bland foods (Yeomans et al., 2004). These results suggest that individuals vary in the extent to which they attempt to restrict their intake and the extent to which they are successful in doing so, as well as the extent to which these individuals respond to external rather than internal appetite cues. However to the present author's knowledge there are no studies which have examined the influence of restraint and disinhibition status on foods with cues for enhanced satiety. Given that those attempting to restrict their intake are the group most likely to benefit from the enhanced satiety concept it is important to investigate whether they respond differently to sensory-enhanced preloads (Hovard et al., 2015).

The present study therefore aimed to further explore whether the enhanced satiety concept is relevant for consumers by investigating how individuals varying in restraint and disinhibition status respond to sensory-enhanced preloads. Given that previous studies have reliably demonstrated that individuals low in restraint and disinhibition tendencies compensate more accurately for energy added to beverages with enhanced sensory characteristics, and report greater satiety (Chambers et al., 2013; Hovard et al., 2015; McCrickerd et al., 2014b; Yeomans & Chambers, 2011; Yeomans et al., 2014) we predicted that this group would respond accordingly in the present study. However, the evidence above suggests that forced preloads may induce disinhibition of restraint in highly restrained participants with a high tendency to disinhibit (Westenhoefer et al., 1994). Given that the typical preload sensory enhancements (viscosity and creamy

flavours) are designed to represent high-calorie, indulgent products, it is plausible that they may induce disinhibition, thus reducing the satiating capacity of sensory-enhanced beverages in those reporting high but not low disinhibition tendencies. As such we anticipated that sensory-enhanced satiety effects may depend on dietary restraint and disinhibition status. This hypothesis was explored using a preload design varying energy content and sensory enhancements, and contrasting the responses of individuals high in restraint and disinhibition, high in restraint but low in disinhibition, and low in both.

### 4.3 Method

#### 4.3.1 Design

A mixed design tested the effect of preload energy content (within subjects; high energy and low energy), and sensory characteristics (within subjects; high sensory and low sensory, where high refers to enhanced sensory characteristics) and restraint and disinhibition status (between subjects; high restraint and high disinhibition, high restraint and low disinhibition, and low restraint and low disinhibition) on subjective and behavioural satiety responses. Expected satiation and satiety were also measured. The preload condition order was counterbalanced using a Williams Square design, within restraint status groups.

#### 4.3.2 Participants

An *a priori* power analysis suggested an appropriate sample size of 28 participants ( $(\beta = .95, \alpha = .05)$ ) in order to observe a medium sized effect of sensory enhancement on energy compensation as previously reported ( $f = .29$  in Yeomans and Chambers, 2011). We were more conservative with our sample size estimate in order to account for interactions between sensory and energy conditions, and restraint status groups, and intended to recruit 20 participants for each restraint group. Participants were recruited

based on their responses to the TFEQ. Upper and lower tertiles of the restraint (R) and disinhibition (D) scales represented cut offs to form high restraint high disinhibition (HRHD;  $R \geq 15$ ,  $D \geq 10$ ), high restraint low disinhibition (HRLD;  $R \geq 15$ ,  $D \leq 5$ ) and low restraint low disinhibition (LRLD;  $R \leq 7$ ,  $D \leq 5$ ) groups. Pre-selection according to these cut-offs was employed to represent extreme values of restraint and disinhibition and thus a true representation of high and low restraint and disinhibition status. By excluding middling scores we reduced the possibility of quasi-arbitrary assignment to groups. Additionally as participants were contacted based on their previous responses they were unaware that the study concerned their dietary habits thus reducing the possibility of demand effects.

Overall 49 participants were recruited, although the HR groups were not fully recruited, possibly because those concerned with their dietary behaviour are less willing to participate in food studies. This idea was supported by an exploratory analysis of the response frequency to the TFEQ at our laboratory. During this study a total of 684 TFEQ respondents were identified as eligible for either the HRHD, HRLD or LRLD groups (out of a total of 3602 respondents). Of these eligible participants 24% were HRHD, 14% HRLD and 62% LRLD, frequencies found to be significantly different by a chi-square test ( $X^2(2) = 265.2$ ,  $p < .001$ ). Of those contacted 17 HRHD, 7 HRLD and 25 LRLD participants were recruited. A further chi square test found no difference in the proportion of those recruited relative to those contacted from each group ( $p = .239$ ). However this is most likely due to the completion of the intended LRLD sample, and thus the cessation of recruitment for this group (whereas if recruitment had continued more of these participants may have been recruited). Overall it is clear that those reporting high restraint are less likely to agree to participate in ingestive behaviour studies. Consequently these groups, in particular the HRLD group, were under-recruited relative to the aims of this study.

Other than relevant restraint status scores, exclusion criteria for the present study were: smoking  $\geq$  five cigarettes per week or using nicotine replacements; taking prescription

medicines other than the contraceptive pill; allergies or aversions to the test ingredients; pregnancy or lactating women; diabetes or diagnosed eating disorders, and self-reported body mass index (BMI)  $\leq 18$  or  $\geq 25$ .

#### 4.3.3 Test foods

##### 4.3.3.1 Standardised Breakfast

A fixed breakfast was served in order to standardise baseline appetite (Table 4.1). The breakfast consisted of 60g commercially available cereal (Crunchy Nut Cornflakes: Kellogg's UK.), a 160g serving of semi-skimmed milk (Sainsbury's Plc. UK), and a 200g glass of smooth orange juice (Sainsbury's Plc. UK). The breakfast was consumed in entirety in the laboratory waiting room.

##### 4.3.3.2 Beverage Preloads

Four beverage preloads based on previous sensory-enhanced satiety studies (Yeomans & Chambers, 2011; Yeomans, Chambers & Ells, 2012; McCrickerd et al., 2012) were used as preloads (see Table 4.2). The beverages consisted of a base of Tropicana Mango Peach and Papaya Juice (PepsiCo, UK), Robinson's peach squash (Britvic, UK), Normandy Natural Fromage Frais (Sainsbury's Plc. UK) and water. Covert energy additions to the high energy (HE) beverages were made by adding maltodextrin (Cargill): a soluble carbohydrate. Sensory enhancements to the high-sensory (HS) versions were made by adding tara gum (Kaly's Gastronomie, FR): a soluble thickening agent, milk caramel flavouring (Symrise GmbH), and vanilla extract (Nielsen-Massey, NL) to enhance thickness and creaminess. Aspartame (Ajinomoto Sweeteners, Europe) was added to the LE beverages to match the subtly sweet taste of maltodextrin. The beverages were colour-matched by adding red and yellow food colourings (Silverspoon, UK). The preloads were served in 320g portions in a transparent glass, and were consumed in entirety.

#### 4.3.3.3 Test lunch

An *ad libitum* test lunch of Conchiglie pasta shells (Sainsbury's Plc. UK) with tomato and basil sauce (Sainsbury's Plc. UK) was provided (Table 4.1). The pasta was cooked for 12 minutes in boiling water, washed and left to stand before portions of 250g sauce and 250g cooked pasta were heated for three minutes in a microwave prior to serving. The pasta was presented in white ceramic bowls which were refilled every time participants consumed 350g such that the bowl could never be consumed entirely. The weight of food consumed was calculated by the Sussex Ingestion Pattern Monitor (SIPM) software every two seconds using a concealed balance (Yeomans, 2000).

*Table 4.1 macronutrient breakdown of a standardised breakfast consumed at the beginning of each test day, and the test lunch consumed 30 minutes following the preload. The test lunch was consumed ad libitum and therefore the below figures relate are per 100g.*

	Amount (g)	Kcal	Carbohydrate	Protein	Fat
Standardised breakfast					
Crunchy Nut Cornflakes	60	241	49	4	3
Semi-Skimmed Milk	160	77	7	6	3
Orange Juice	200	84	17	1.2	1
Total		402	73	11.2	7
Test lunch per 100g					
Pasta (cooked weight)		160	34	4.4	0.6
Tomato Sauce		58	7	1.6	2.5
Total	per 100g	109	21	3	1.5

*Table 4.2 Formulations and macronutrient breakdown (grams per beverage) for four beverage preloads varying in energy content (achieved through maltodextrin additions) and sensory characteristics (tara gum, vanilla essence, milk caramel). H refers to high, L low, E energy, S sensory characteristics.*

	LELS	LEHS	HELS	HEHS
Ingredients				
Mango Peach and Papaya Juice	100	100	100	100
Peach Squash	35	35	35	35
Fromage Frais	55	55	30	30
Tap Water	130	128	100	98
Maltodextrin	0	0	55	55
Tara Gum	0.2	1.4	0	1.3
Vanilla Essence	0	1	0	1
Milk Caramel Flavouring	0	0.8	0	0.8
Aspartame	0.03	0.03	0	0
Macronutrients				
Carbohydrates	12.6	12.6	63.8	63.8
Protein	5.0	5.0	3.0	3.0
Fat	0.1	0.1	0	0
Energy Content (Kcal)	75.4	75.4	271.9	271.9

#### 4.3.4 Visual analogue scale ratings

Visual analogue scales (VAS) were used to collect subjective appetite ratings, sensory ratings relating to the preloads, and expected satiation and satiety ratings. The VAS were presented using the Sussex Ingestion Pattern Monitor (SIPM) software (Yeomans, 2000) and appeared on a computer screen as a continuous bar upon which participants were required to drag a pointer to indicate their rating. This generated a score between 0-100. Appetite and dummy mood ratings were collected pre and post-preload, pre-lunch, post-taste of the *ad libitum* test meal, and post-test meal. ). The rating questions were presented in the format “how <rating> (hungry, full, thirsty, anxious, calm, clear-headed, energetic, happy, headache, nauseous, and tired) do you feel?” anchored by “not at all <rating>” and “extremely <rating>”. Additionally prospective consumption was collected in the format “how much do you think you could eat right now?”, anchored by “nothing at all” and “a great deal”, and desire to eat in the format “how much of a desire to eat do you feel right now”, anchored by “no desire to eat at all” and “extremely strong desire to eat”. Following preload tasting sensory ratings (thick, creamy, pleasant, sweet, and familiar) were collected in the format “how <rating> is the beverage?” anchored by “not at all <rating>” and “extremely <rating>”. Expected satiation and satiety ratings were measured in the format “how hungry/ full would you expect to be immediately/ one hour later after consuming a glass of the drink the size of the one in front of you?”, anchored by “not at all hungry/ full” and extremely hungry/full”. The rating order in each section was randomised.

#### 4.3.5 Procedure

The procedure for each test session is illustrated in Figure 4.1. Participants were invited by email, through a university online recruitment system and through distribution of flyers on the university campus to complete an on-line version of the TFEQ. Respondents also completed demographic questions and questions regarding food allergies and aversions. Those who were eligible based on negative matches to the



exclusion criteria and falling into one of the HRHD, HRLD or LRLD restraint status groups were then contacted by email and invited to take part in a food and mood experiment. Participants attended the laboratory for testing on four non-consecutive days, and were instructed to consume nothing but water from 23.00hrs the evening before each session. Participants attended the laboratory at an arranged time between 08.30hrs and 10.30hrs to consume the standard breakfast in full, before a three-hour interval in which they refrained from eating, drinking (excluding water), or vigorous exercise. They then returned to the laboratory where the SIPM software was used to guide participants through the remaining study procedure. They first completed baseline (pre-preload) mood and appetite ratings. One of the beverage preloads was then presented and participants were instructed to taste and rate the beverage on sensory dimensions, and expected satiation and satiety, before consuming the beverage in full within ten minutes. Further mood and appetite ratings were then completed, before participants waited in the laboratory waiting room for 30 minutes. Participants returned to the cubicle and completed mood and appetite ratings before a sample of pasta and tomato sauce (20g) was tasted and appetite was rated again. Additionally sensory ratings were presented to check that test meal pleasantness was equal across preload conditions. A 500g bowl of pasta and sauce was then presented and participants were informed that they could consume it *ad libitum* and that the software would prompt them to obtain a refill before the bowl was finished (and that this would repeat indefinitely until they indicated that they were comfortably full). The pasta was placed on top of a balance concealed by a place mat which measured the weight of the pasta every two seconds. Following consumption of 350g the SIPM software instructed participants to stop eating and call the experimenter for a refill. Following participants' indication that they were comfortably full final mood and appetite ratings were administered. Participants completed no more than two sessions in one week, with only the beverage preload differing on each occasion. Participants were awarded £40 or course credit as compensation for their time.

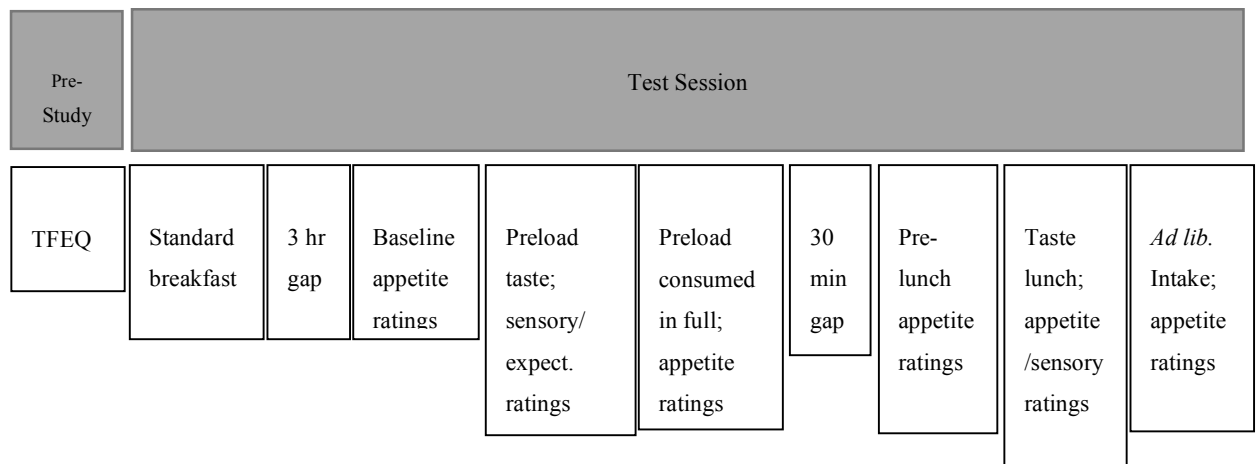


Figure 4.1 test day procedure, repeated for each preload on non-consecutive days in a counterbalanced order. Participants first completed the TFEQ before the test session. At the test session participants consumed a standardised breakfast followed by a 3-hour interval. Appetite ratings were completed following the interval and throughout the session. A preload was consumed and sensory, appetite expectation ratings and actual appetite ratings were completed before a 30-minute interval. A test meal was then administered with further appetite and sensory ratings.

The data were analysed using analysis of variance (ANOVA). Participants' intake of the *ad libitum* test meal was analysed using a three-way mixed ANOVA comparing main effects and interactions between energy content, sensory context and restraint status. A key question was the extent to which the sensory enhancements would improve compensation for the covertly added energy and whether this differed between restraint status groups. An energy compensation measure was calculated. This measure represents the reduction in energy intake of the test meal following HE preloads, relative to the LE control preloads, represented as a percentage of the original difference in energy between the preloads. In other words it is the degree to which participants respond to the energy additions by reducing their intake later. A compensation score of 100% would suggest a reduction in subsequent intake exactly equivalent to the extra energy consumed in the preload. These compensation scores were compared between the sensory variations of the HE beverage, and the extent to which this depended on restraint status was analysed using a two-way mixed ANOVA (sensory context and restraint status). Interpretation of non-significant effects for this analysis was

supplemented by Bayes factors (B). This statistic represents the probability of the experimental and null hypotheses given the data, based on prior estimates of effects that would support the theory at test (Dienes, 2014). A B of  $\leq 0.3$  is generally considered as support for the null hypothesis, whilst a B of  $\geq 3$  is considered as support for the tested theory, and B between these scores suggests that the data do not sensitively distinguish between the null and experimental hypotheses (Dienes, 2014). This is in contrast to common interpretations of non-significance as a lack of meaningful effect (where contrarily it may suggest insensitivity rather than support for the null). In order to estimate meaningful effects the difference between HS and LS compensation scores found by Yeomans and Chambers (2011; 69%) was considered a plausible interesting effect. Thus the B reported here represents the relative support for a null hypothesis and the hypothesis that compensation differences between sensory context groups is equivalent to Yeomans and Chambers' (2011) findings.

Self-reported appetite was recorded throughout the test session using ratings of hunger, fullness, prospective consumption, desire to eat, and thirst. A composite satiety score was generated to summarise these ratings. This measure was the average of each participant's appetite ratings (excluding thirst, and with hunger, prospective consumption and desire to eat reversed to interpret as satiety ratings). These ratings were analysed using four-way mixed ANOVAs comparing rating time, beverage sensory context and energy content and restraint status group. Where there were interactions only key points (baseline, post-preload and pre-lunch) were assessed in more detail by isolating the relevant effects with simpler ANOVAs. Expected satiation and satiety, and sensory ratings were analysed using two-way ANOVAs (energy and sensory context). All reported SEMs are adjusted for within-subjects variation.

## 4.4 Results

Data from four participants with energy compensation scores two standard deviations above or below the mean were excluded from all analyses. Reported SEM is adjusted for within-subjects variation.

### 4.4.1 Intake

Overall intake was significantly lower following HE preloads,  $F(1, 42) = 11.43, p = .002, \eta_p^2 = .21$ : (Table 4.3). However, there were no overall significant effects of sensory context,  $F(1, 42) = 1.04, p = .313, \eta_p^2 = .02$ , or participants' restraint status  $F(2, 42) = 0.49, p = .619, \eta_p^2 = .02$ . There was however a significant three-way interaction between energy, sensory context and restraint,  $F(2, 42) = 3.68, p = .034, \eta_p^2 = .15$ . Closer inspection found that the HRHD group reduced their intake following HE preloads ( $p = .013$ ), although this depended on the sensory context ( $p = .042$ ). This group consumed least following the HELS and most following the LELS. In order to assess whether this constituted a rebound effect (which would be supported by greater intake following the LEHS than the LELS) the LE preloads were compared, although the differences were not found to be significant ( $p = .409$ ). Additionally, the LRLD group responded to the energy in the beverages by consuming significantly less following HE preloads ( $p = .018$ ), but this energy effect did not depend on sensory context ( $p = .749$ ).

*Table 4.3 – participants consumed less of a test meal following high-energy than low-energy preloads (mean kcal intake  $\pm$  SEM) and this interacted with sensory characteristics and restraint status. Participants reporting high dietary restraint and disinhibition consumed less following the high-energy preload without sensory enhancements than the other preloads. Participants low in restraint and disinhibition consumed less following high-energy preloads but this did not depend on sensory characteristics.*

	LELS	HELS	LEHS	HEHS
HRHD	912 $\pm$ 58.3	608.7 $\pm$ 46.5	841.8 $\pm$ 40.5	819.8 $\pm$ 46.8
HRLD	798.5 $\pm$ 36.6	788.8 $\pm$ 57	934.7 $\pm$ 107	729 $\pm$ 66.5
LRLD	779.4 $\pm$ 34.2	685.9 $\pm$ 33.6	794.6 $\pm$ 33.1	676.9 $\pm$ 44.9

#### 4.4.2 Energy Compensation

One key interpretation of the intake data is the degree to which participants respond to the covert energy additions by reducing their intake of a subsequent meal. The intake analysis above suggested differences in the way participants of different restraint statuses responded to energy consumed in different sensory contexts. This was explored further by assessing the percentage of additional energy consumed in the HE preloads that was compensated for by reducing subsequent intake. Figure 4.2 suggests that the HRHD group compensated more accurately for the energy added without enhanced sensory characteristics, whilst the HRLD and LRLD groups responded more accurately to the energy consumed in the HS contexts. This was partially supported statistically. There was no significant main effect of sensory context on compensation for the covert energy manipulation,  $F(1, 42) = 0.08$ ,  $p = .783$ ,  $\eta_p^2 = .002$ , and no significant main effect of restraint status  $F(2, 42) = 0.36$ ,  $p = .702$ ,  $\eta_p^2 = .02$ . However there was a significant interaction,  $F(2, 42) = 3.68$ ,  $p = .034$ ,  $\eta_p^2 = .15$ . On inspection of the differences in compensation within restraint groups the only significant difference was

in the HRHD group where the LS version was compensated for significantly better than the HS version,  $t(14) = 2.24, p = .042$ . This is the opposite effect to those found previously with unrestrained participants, who compensated more accurately for energy consumed in HS versions (Chambers et al., 2013; McCrickerd et al., 2014b; Yeomans & Chambers, 2011; Yeomans et al., 2014). Presently, the HRLD and LRLD groups both compensated more accurately for the HEHS preload, but these effects did not reach significance (both  $p \geq .343$ ). Bayes factors (B) demonstrated that the data did not sufficiently support the null hypothesis ( $B = 1.36$  and  $0.8$  for the HRLD and LRLD groups respectively), suggesting that the data should be considered insensitive rather than support for no difference between the preload conditions for compensation scores (see Dienes, 2014). Given that potential rebound effects from the LEHS beverage could exaggerate compensation scores the HEHS scores were also compared to the LELS scores. In the HRHD group compensation was  $46.8\% (\pm 43.2)$ , suggesting that the poor compensation for the HEHS beverage illustrated in figure 4.2 was partly driven by higher intake of the LEHS (a putative rebound effect, although as described above, the difference between the LE preloads in this group did not reach significance). Meanwhile compensation in HRLD group was  $35.3\% (\pm 26.5)$  and in the LRLD group  $52.0\% (\pm 35.8)$ , weaker than using the traditional control groups, suggesting again that the compensation scores are exaggerated by greater intake following LEHS than LELS preloads (although again these differences in intake did not reach significance, both  $p \geq .346$ ).

There were no significant effects of sensory context, energy content or restraint status group (all  $p \geq .150$ ) on test-meal palatability, suggesting that this did not drive differences in intake or compensation.

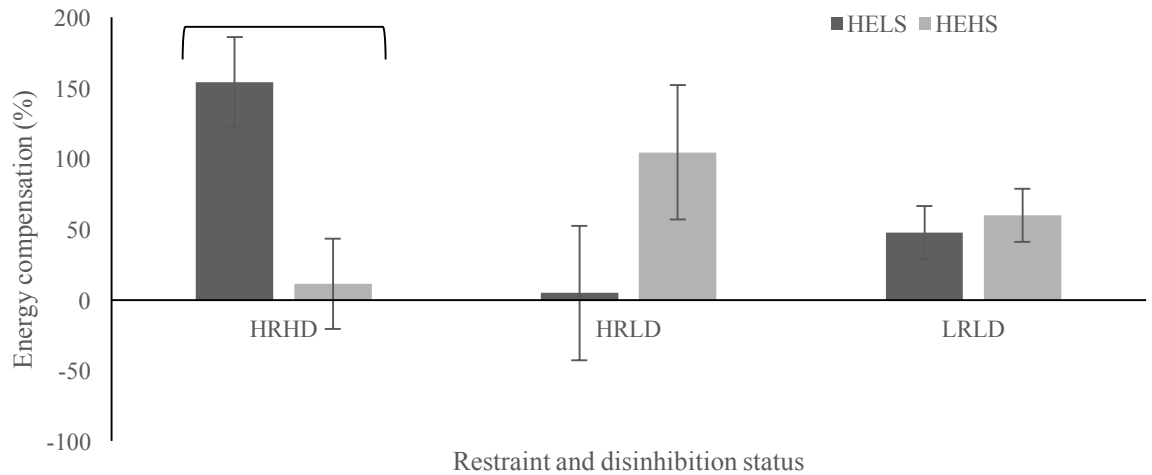


Figure 4.2 There was an interaction between preload and restraint status on compensation for covertly added energy in the HELS and HEHS preloads (% of covert energy addition accounted for by reduction in test meal intake). HRHD participants compensated significantly more accurately for HELS preload than HEHS). Bayes factors show insensitivity to observe greater compensation for HEHS preload in HRLD and LRLD groups. Error bars are  $\pm$  SEM.

#### 4.4.3 Appetite Ratings

Analyses of all appetite ratings revealed significant differences over the course of the test session (all  $p \leq .001$ ,  $\eta_p^2 \geq .32$ ), with satiety increasing following the preload, decreasing over the course of the inter-meal interval, and peaking following *ad libitum* intake of the test meal (see Figure 4.3). There were no significant differences between energy, sensory or restraint status conditions at baseline for any rating (all  $p \geq .119$ ), although participants were borderline-significantly hungrier in the HS conditions ( $p = .062$ ).

Figure 4.3 suggests that the HRHD group reported greater satiety following the HELS preload. However, there were no overall differences between energy, sensory or restraint status for the composite satiety measure (all  $p \geq .106$ ). There was a borderline three-way interaction between restraint status, sensory condition and rating time,  $F(6, 126) = 2.15$ ,  $p = .052$ ,  $\eta_p^2 = .09$ . Closer analysis of key time points (after the preload and

30 minutes later, before lunch) found no significant effect of sensory condition (both  $p \geq .405$ ), but there was a borderline significant effect of restraint status after consuming the preload ( $p = .059$ ), with the LRLD group reporting higher satiety than the HRLD ( $p = .032$ ) and trending towards higher satiety than the HRHD group ( $p = .110$ ).

The difference in hunger ratings over time depended on the preload energy content,  $F(3, 126) = 2.80, p = .043, \eta_p^2 = .06$ . There was also an interaction between the sensory condition, restraint status and rating time  $F(6, 126) = 2.76, p = .015, \eta_p^2 = .12$ . Closer inspection of the key time points suggested neither the sensory, energy nor restraint groups differed following the beverage, or 30 minutes later (all  $p \geq .181$ ).

Similarly fullness ratings over time depended on preload energy content,  $F(3, 126) = 4.57, p = .004, \eta_p^2 = .10$ . Unexpectedly there was a trend for higher fullness in the LE conditions after the preload ( $p = .086$ ), but the mean difference was negligible ( $M = 3.3$ , for example Sadoul, Schuring, Mela, & Peters, 2014, suggest a difference of at least 15 VAS points to correspond to differences in intake), and there was no difference 30 mins later ( $p = .161$ ).

Similarly the time effect for desire to eat ratings depended on preload energy content,  $F(3, 126) = 5.09, p = .002, \eta_p^2 = .11$ . There were no differences following the preload ( $p = .392$ ). There was a trend for higher desire to eat following LE preloads 30 minutes later ( $p = .062$ ), but again the mean difference was negligible ( $M = 3.8$ ).

Prospective consumption depended on restraint status,  $F(2, 42) = 2.80, p = .072, \eta_p^2 = .12$ , with the LRLD group reporting lower ratings than the HRLD group ( $p = .044$ ) and trending towards lower ratings than the HRHD group ( $p = .104$ ).

Finally thirst ratings were also compared demonstrating that they changed over the test session,  $F(3, 126) = 23.47, p < .001, \eta_p^2 = .36$ . There was also an overall effect of sensory context ( $p = .031$ ) which depended on restraint status,  $F(2, 42) = 3.58, p =$



.037,  $\eta_p^2 = .15$ . The HRLD group reported higher thirst in the LS conditions ( $M = 45.2$ ,  $SEM = 5.24$ ) than the HS conditions ( $M = 33.92$ ,  $SEM = 6.4$ ). Mean differences in the other restraint status groups were negligible ( $M = 3.2$ , and  $-1.7$  for differences in thirst between the LS and HS beverages by the HRHD and LRLD groups respectively).

#### 4.4.4 Expected satiation and satiety

Expected satiation (expected fullness and hunger immediately following the beverage) and satiety (expected fullness and hunger one hour after consuming the beverage) were compared across the preloads by restraint status groups (see Table 4.4). There were no main effects of energy content, sensory context or restraint status on immediate fullness (all  $p \geq .423$ ), but there was an interaction between energy content and sensory context,  $F(1, 42) = 5.13$ ,  $p = .029$ ,  $\eta_p^2 = .11$ . Greater immediate fullness was expected in the HEHS than HELS condition, but also, unexpectedly, in the LELS than the LEHS condition.

There were also no main effects on expected later fullness (all  $p \geq .140$ ) other than a borderline effect of sensory context,  $F(1, 42) = 3.69$ ,  $p = .062$ ,  $\eta_p^2 = .08$ . However, unexpectedly, the LS conditions were expected to deliver greater fullness. This was likely driven by a borderline-significant interaction with restraint status  $F(2, 42) = 2.91$ ,  $p = .065$ ,  $\eta_p^2 = .12$ , with the HRLD group reporting lower expected later fullness for the HS preloads, with all other ratings across groups similar.

There were no effects of energy content, sensory context or restraint status on expected immediate or later hunger (all  $p \geq .128$ ). There were no interactions other than between energy content and restraint status for expected later hunger,  $F(1, 42) = 3.77$ ,  $p = .031$ ,  $\eta_p^2 = .15$ . The HRHD group expected greater hunger following HE preloads, although the HRLD group expected greater hunger following LE preloads.

#### 4.4.5 Sensory analysis

Key sensory characteristics of thickness, creaminess and pleasantness were compared, demonstrating that the manipulations were largely rated as designed (see Table 4.4). As expected the HS context generated greater creaminess ratings. This was backed up by an effect of sensory context,  $F(1, 44) = 10.75, p = .002, \eta_p^2 = .20$ , but not energy content  $F(1, 44) = 0.18, p = .677, \eta_p^2 = .004$ , and no interaction  $F(1, 44) = 0.91, p = .347, \eta_p^2 = .02$ . Additionally, the HS context preloads were reported as being thicker than the LS context preloads,  $F(1, 44) = 43.55, p < .001, \eta_p^2 = .50$ . However unexpectedly there was also a borderline effect of energy content  $F(1, 44) = 3.90, p = .055, \eta_p^2 = .08$ , and an interaction,  $F(1, 44) = 17.65, p < .001, \eta_p^2 = .29$ . Closer analysis found that the HELS was considered thicker than the LELS,  $t(44) = 4.19, p < .001$ , although, as designed, the HS beverages did not differ,  $t(44) = 1.68, p = .100$ . There were no differences between energy and sensory conditions for pleasantness, and no interaction (all  $p \geq .088$ ). Unexpectedly the beverages differed in rated sweetness based on their energy content,  $F(1, 44) = 10.34, p = .002, \eta_p^2 = .19$ , but not their sensory context,  $F(2, 44) = 1.46, p = .234, \eta_p^2 = .03$ . The HE beverages were rated as sweeter than the LE beverages although the mean difference was small ( $M = 6.2$ ). The beverages did not differ by sensory context or energy content on ratings of familiarity (both  $p \geq .201$ ). There were no effects of restraint status (all  $p \geq .261$ ) on any rating apart from pleasantness,  $F(2, 42) = 3.65, p = .034, \eta_p^2 = .15$ . Here the HRHD participants rated all of the beverages as less pleasant than the HRLD participants ( $p = .015$ ), and borderline significantly less pleasant than the LRLD participants ( $p = .063$ ).

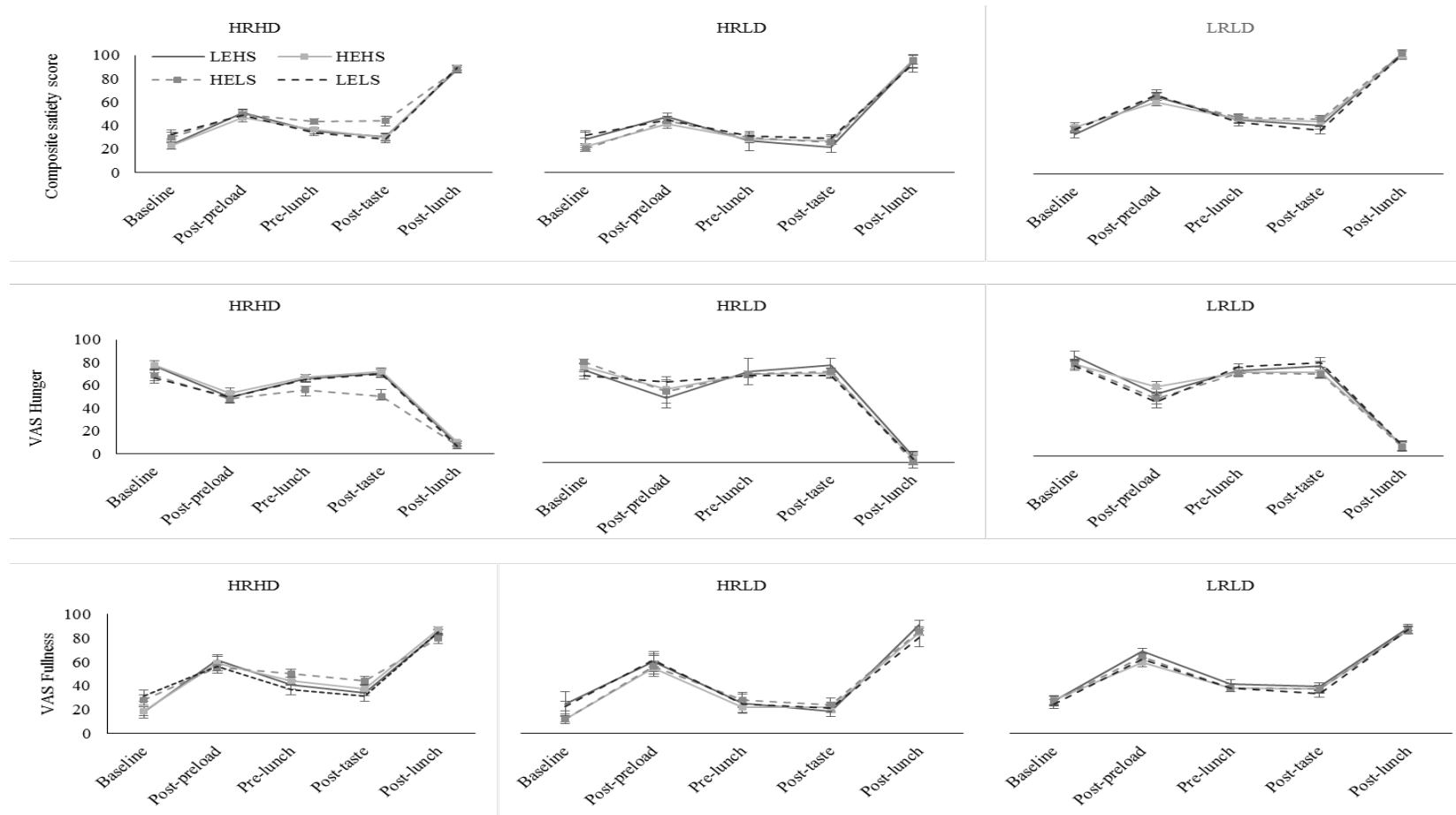


Figure 4.3 Mean VAS composite satiety score, hunger and fullness ratings across the test session by restraint status grouping. Solid lines represent HS beverages, dashed lines are LS beverages, markers represent HE beverages. Error bars are  $\pm$  SEM. Appetite tended to decrease following intake of the preload and test lunch, recovering over time after both. The composite satiety measure showed no  $f$ -differences between beverage energy content or sensory characteristic and no differences between restraint groups. Hunger tended to be higher following low-energy preloads than high-energy. Fullness was higher following low-energy preloads but the mean differences were negligible. No other differences were significant.

*Table 4.4 Mean ( $\pm$  SEM) expected satiation (full and hungry immediately) and satiety (full and hungry one hour later) and sensory ratings of the beverages by restraint status groups. There were no main effects between energy content, sensory characteristics or restraint group on appetite expectations. The HS preloads were rated as thicker and creamier than LS preloads. Unexpectedly the HELS beverage was rated as thicker than the LELS. There were no differences between the preloads on pleasantness or familiarity ratings. Unexpectedly the HE preloads were rated as sweeter than LE preloads, but the differences were small.*

		Full Immediately	Full Later	Hungry Immediately	Hungry Later	Thick	Creamy	Pleasant	Sweet	Familiar
HRHD	LELS	67.5 $\pm$ 2.5	69.7 $\pm$ 4.9	67.5 $\pm$ 3.7	63.5 $\pm$ 2.7	41.5 $\pm$ 3.1	59.1 $\pm$ 2.5	59.5 $\pm$ 3.3	75.9 $\pm$ 1.6	70.1 $\pm$ 4.2
	HELS	46.2 $\pm$ 3.2	46.6 $\pm$ 5.9	45.8 $\pm$ 5.1	44 $\pm$ 4.4	53.5 $\pm$ 3.4	66.1 $\pm$ 2.7	53.7 $\pm$ 2.5	81.3 $\pm$ 2.7	83.1 $\pm$ 2.6
	LEHS	40.7 $\pm$ 3.6	40.6 $\pm$ 4.8	35.8 $\pm$ 3.1	42 $\pm$ 4.5	70.2 $\pm$ 2.9	72.4 $\pm$ 3	50.5 $\pm$ 2.9	67.3 $\pm$ 4.4	70.1 $\pm$ 4.5
	HEHS	61.1 $\pm$ 4.7	68.9 $\pm$ 5.7	52.8 $\pm$ 3.8	64.3 $\pm$ 4.9	62.7 $\pm$ 3.7	64.9 $\pm$ 4.2	56 $\pm$ 4.7	80.4 $\pm$ 2.4	73.9 $\pm$ 4.4
HRLD	LELS	52.8 $\pm$ 6.9	67.7 $\pm$ 11.5	69.8 $\pm$ 10.3	55.8 $\pm$ 6	62.3 $\pm$ 2.4	58.5 $\pm$ 7.1	76.8 $\pm$ 3.5	67.8 $\pm$ 2.6	76.5 $\pm$ 10.3
	HELS	39.3 $\pm$ 5.6	43.8 $\pm$ 11.4	17.3 $\pm$ 9.8	21.5 $\pm$ 5.4	73 $\pm$ 3.7	52.8 $\pm$ 8.8	85 $\pm$ 3.7	71.8 $\pm$ 1.8	48.7 $\pm$ 7.6
	LEHS	44.8 $\pm$ 6.5	47.2 $\pm$ 4	39.3 $\pm$ 10.3	27.5 $\pm$ 3.5	73.2 $\pm$ 3.7	64.8 $\pm$ 7.6	76.2 $\pm$ 4.1	67 $\pm$ 2.3	63.5 $\pm$ 8.3
	HEHS	78.5 $\pm$ 5.2	54.5 $\pm$ 4.4	69 $\pm$ 7.3	64.7 $\pm$ 4.6	68 $\pm$ 3.2	62.8 $\pm$ 3.3	81.7 $\pm$ 1.5	71.2 $\pm$ 1.3	67.5 $\pm$ 5
LRLD	LELS	72.6 $\pm$ 2.3	72.8 $\pm$ 3.4	72.9 $\pm$ 4.6	64.6 $\pm$ 3.2	45.7 $\pm$ 2.9	64.1 $\pm$ 1.6	63.4 $\pm$ 2.2	71.8 $\pm$ 1.7	74.3 $\pm$ 3.1
	HELS	42.9 $\pm$ 2.6	40.9 $\pm$ 3.5	47 $\pm$ 2.9	40.3 $\pm$ 3.5	58.3 $\pm$ 2.3	63.6 $\pm$ 2.1	72.6 $\pm$ 1.8	78.9 $\pm$ 1.8	69.5 $\pm$ 3.3
	LEHS	34.2 $\pm$ 3.5	29.9 $\pm$ 3.4	32.3 $\pm$ 4.2	26.6 $\pm$ 3.9	67.8 $\pm$ 2.2	71.7 $\pm$ 2.3	67.3 $\pm$ 1.9	73.6 $\pm$ 2.1	69.3 $\pm$ 3.7
	HEHS	53.4 $\pm$ 3.9	53 $\pm$ 4.1	54.4 $\pm$ 4.3	55.5 $\pm$ 3.2	65.4 $\pm$ 2.2	71.8 $\pm$ 1.8	67.6 $\pm$ 1.8	76.1 $\pm$ 1.7	63.1 $\pm$ 4.3

## 4.5 Discussion

The present study aimed to assess whether sensory-enhanced satiety can be beneficial to real consumers by measuring its efficacy in consumers varying in dietary restraint and disinhibition. A previous study suggested that those concerned with their dietary behaviour would be more likely to be interested in the enhanced satiety concept (Hovard et al., 2015), although all prior studies of the concept have actively excluded such individuals in order to guard against floor effects (Chambers et al., 2013; Hovard et al., 2015; McCrickerd et al., 2014b; Yeomans & Chambers, 2011; Yeomans et al., 2014). Thus it was necessary to explore whether enhanced satiety effects generalise to these individuals. We hypothesised that the LRLD group would, as previously documented (Chambers et al., 2013; Hovard et al., 2015; McCrickerd et al., 2014b; Yeomans & Chambers, 2011; Yeomans et al., 2014), experience greater satiety and compensate more accurately for energy loads consumed in an enhanced sensory context. However restraint theory suggests that a challenge to restrained individuals' ability to restrict their intake may result in overeating if those individuals also have a tendency to disinhibit (Haynes et al., 2003; Westenhoefer et al., 1994; Yeomans & Coughlan, 2009). Therefore, given that the enhanced satiety manipulation presents preloads with sensory characteristics that allude to high caloric content it was hypothesised that such individuals might overeat following this preload, thus reducing the effect of enhanced satiety. The present findings partially support these hypotheses as the HRHD group compensated more accurately for the energy consumed in the non-enhanced sensory context. The intake data suggest that this effect was driven by decreased intake of the HEHS beverage *and* increased intake of the LELS beverage. If the enhanced sensory characteristics acted as a disinhibiting stimulus this would be the case for both HS preloads, however whilst the results suggest elevated levels of intake of the HEHS relative to the other restraint status groups, this group did not consume more of the LEHS beverage. Thus whilst HRHD participants behaved contrarily to effects found previously, it is unclear as to whether this was due to a disinhibition effect caused by the preload characteristics. Meanwhile the HRLD and LRLD groups

compensated more accurately for energy consumed with enhanced-sensory cues although these effects did not reach statistical significance. Bayes factors suggested that the data did not distinguish between support for null effects and compensation differences. Thus this should be considered as insensitive data rather than evidence for minimal compensation differences (e.g. Dienes, 2014).

There were few meaningful effects in the subjective appetite data, although immediately following the preload the LRLD reported higher satiety than the other groups. This is consistent with early conceptions of restraint theory which suggested that low restrained participants were more adept at responding to internal satiety cues (Heatherton et al., 1989). However later ideas about restraint theory suggested that this notion is limited by early conflation of restraint and disinhibition concepts (e.g. Heatherton, Herman, Polivy, King, & McGree, 1988; Westenhoefer et al., 1994; Westenhoefer, 1991). A later study which separated restraint and disinhibition concepts found greater responsiveness palatability (i.e. an external food cue), by those high in restraint *and* disinhibition (Yeomans et al., 2004). Similarly, the present data suggest that low scores in both dimensions are related to higher sensitivity to fullness sensations following intake of a preload, indicated by greater VAS satiety ratings.

The clarity of the present results is limited by power issues. Whilst there was sufficient power to observe overall effects, difficulty with recruiting the high restrained participants lead to low numbers in these groups (particularly in the HRLD group). This is a clear limitation of the present study and may have influenced some effects. For example, there was a large increase in compensation accuracy in the HRLD group for the HS preloads, as predicted. However, the compensation effect did not reach significance, possibly as a result of insufficient power. This is supported by closer analysis using a Bayes factor. This statistic quantifies the level of support for the experimental hypothesis and the null hypothesis given the data (Dienes, 2014). Based on suggested interpretation guidelines (Dienes, 2014) the present analysis suggested insufficient evidence to distinguish support for the null hypothesis or the experimental

hypothesis. Therefore rather than evidence of limited differences in compensation between sensory contexts, these findings should be considered preliminary explorations of a potentially interesting effect: that high restraint and disinhibition counters enhanced satiety, whilst high and low restraint groups with low disinhibition tendencies display enhanced satiety for enhanced sensory context beverage preloads. In other words disinhibition status may be an important factor in determining the efficacy of the enhanced satiety concept for restrained participants. This needs to be explored with greater numbers of participants for substantiation.

Relatedly, exploratory analysis of responses to the study recruitment process demonstrated a significantly higher frequency of TFEQ responses by LRLD participants than either HR group. This may reflect a lower willingness to participate in ingestive behaviour studies by highly restrained participants. This hypothesis is plausible given that such participants are characterised by concern for dietary issues (Herman & Polivy, 1983), and therefore may not wish to engage in studies which could involve pressure to consume high calorie foods which would break a diet rule. This hypothesis would have implications for recruitment to ingestive behaviour studies, whereby if not controlled, study samples are likely to be biased towards recruiting low restrained participants.

A further limitation of the present study is that although the HS beverages were matched for key sensory attributes (thickness and creaminess) as intended, the HE version of the LS beverages was considered thicker than the LE version. This is likely due to the addition of maltodextrin to generate the covert energy addition. The preload formulations attempted to counter this by introducing a small addition of tara gum to the LE version to match the thickness. However this appears to have been unsuccessful in the present study. One implication of this non-match for perceived viscosity is that it may have generated a sensory cue for enhanced satiety in the HELS preload, relative to the LE version. However if this was the case it would be predicted that energy compensation would be enhanced for the HELS beverage. This was the case for the HRHD participants, but compensation for this preload was poor in the other groups.

This finding along with that the HS preloads were rated as significantly thicker and creamier than both LS preloads make it unlikely that this unexpected greater thickness in the HELS preload influenced satiety effects.

More generally this study also demonstrated that energy compensation scores can be exaggerated by increased intake of low energy preloads with enhanced sensory characteristics. This has previously been interpreted as a rebound effect (Yeomans & Chambers, 2011). In the present study whilst all groups consumed more following the low energy beverages in the enhanced sensory context, intake did not differ significantly, and so a true rebound effect was not supported. Nonetheless this increased intake of the LEHS preloads exaggerated compensation scores for the HEHS preloads (a difference of nearly 70% in the HRLD group). Therefore it is important to assess the most appropriate control groups for compensation analyses. In many studies compensation has been calculated within sensory condition groups (Chambers et al., 2013; McCrickerd et al., 2014b; Yeomans & Chambers, 2011; Yeomans et al., 2014) however this makes it unclear whether compensation effects are driven by reduced intake of HE preloads, or increased intake of LE preloads consumed in an enhanced sensory context.

The present study has implications for the utility of sensory enhanced satiety to consumers. Those high in restraint and disinhibition appear to compensate more accurately for covert energy loads designed to appear as low calorie than high calorie, which could be interpreted as a disinhibition effect. Meanwhile, although unclear in the present study, previous findings suggest that participants reporting low restraint and disinhibition produce enhanced compensatory responses for beverages designed to appear as highly-caloric (Chambers et al., 2013; Hovard et al., 2015; McCrickerd et al., 2014b; Yeomans & Chambers, 2011; Yeomans et al., 2014). Therefore whilst previous studies have suggested that those concerned with their dietary behaviour would be more likely to benefit from the enhanced satiety concept (Hovard et al., 2015) the present study suggests that enhanced sensory preloads may generate undesired, poor



compensatory responses in those individuals. The focus group from the previous study also suggested that consumers with time pressures may be interested in the enhanced satiety concept. On the basis of the present results these consumers may be a more viable target for enhanced satiety. Future studies need to substantiate whether enhanced satiety is relevant when preloads are consumed in situations characterising time-limited consumers. For example, high eating rate (de Graaf, 2011) and distraction (Brunstrom & Mitchell, 2006; Higgs & Woodward, 2009; Oldham-Cooper et al., 2011; Robinson et al., 2013) are both factors which may limit satiety, and are likely to be features of time-limited consumers' eating contexts. Whether sensory-enhanced satiety can counter these satiety-limiting effects is currently unclear.

In conclusion this study provides preliminary evidence that differences in restraint and disinhibition status reflect differences in response to the enhanced satiety concept. Most clearly participants who report high levels of restraint and disinhibition compensate poorly for covert energy consumed with enhanced sensory characteristics. A tentative explanation for this is that as the enhanced sensory beverages are designed to appear as high-calorie they may produce a disinhibition effect in participants with a tendency towards disinhibition. Whilst the highly restrained and non-restrained participants reporting low disinhibition responded by compensating more accurately for enhanced sensory beverages these findings did not reach significance. This was probably due to power issues, and analysis using Bayes factor suggested that these findings did not support a null effect either. Therefore this preliminary finding needs further exploration. Importantly these findings suggest that whilst participants who are concerned with their dietary behaviour are more likely to be interested in enhanced satiety products they may produce unwanted poor compensation effects. Therefore it may be more fruitful to consider the enhanced satiety concept as a means to tackling unwanted hunger for the time-pressured consumer, not relying on diet concerned participants *per se*. The effects of sensory-enhanced satiety in such consumers is currently unclear. A final exploratory finding from this study is that highly restrained participants may be underrepresented in

ingestive behaviour study recruitment drives. Therefore future studies should endeavour to control this variable to ensure unbiased samples.

#### 4.6 Author contributions

PH designed the study and materials, collected and analysed the data and wrote the manuscript, with supervisory commentary from MY.

5 Paper 4: Assimilation of healthy and indulgent impressions from labelling influences fullness but not intake or sensory experience

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## 5.1 Abstract

### 5.1.1 Background

Recent evidence suggests that products believed to be healthy may be over consumed relative to indulgent or highly caloric products. The extent to which these effects relate to expectations from labelling, oral experience, or assimilation of expectations is unclear. Over two experiments we tested the hypotheses that healthy and indulgent information could be assimilated by oral experience of beverages and influence sensory evaluation, expected satiety, satiation and subsequent appetite. Additionally we explored how expectation-experience congruency influenced these factors.

### 5.1.2 Results

Results supported some assimilation of healthiness and indulgent ratings – study one showed that indulgent ratings enhanced by the indulgent label persisted post-tasting, and this resulted in increased fullness ratings. In study two congruency of healthy labels and oral experience promoted enhanced healthiness ratings. These healthiness and indulgent beliefs did not influence sensory analysis or intake – these were dictated by the products themselves. Healthy labels, but not experience, were associated with decreased expected satiety.

### 5.1.3 Conclusions

Overall labels generated expectations, and some assimilation where there were congruencies between expectation and experience, but oral experience tended to override initial expectations to determine ultimate sensory evaluations and intake. Familiarity with the sensory properties of the test beverages may have resulted in the use of prior knowledge, rather than the label information, to guide evaluations and behaviour.

## 5.2 Background

Amid concerns regarding obesity rates and the related disease risks (Mozaffarian et al., 2015) attention has turned to healthfulness. Consequently a common marketing strategy is to highlight products' health-relevant properties. However it is unclear whether consumers benefit from these marketing methods. Cognitive and sensory cues influence various dimensions of eating behaviour from initial food choice decisions (Grabenhorst et al., 2013) to sensory evaluation (Shankar, Levitan, Prescott, & Spence, 2009; Yeomans et al., 2008), intake decisions (Fay et al., 2011; McCrickerd et al., 2014a) and satiety response (Chambers et al., 2013; Crum et al., 2011; McCrickerd et al., 2014b; Wooley, 1972; Yeomans & Chambers, 2011; Yeomans et al., 2014). Thus it is plausible that marketing healthiness may influence eating behaviour.

Several studies suggest that products believed to be healthy are over-consumed relative to believed indulgent or highly caloric products despite decreased palatability expectations (Chandon & Wansink, 2007; Crum et al., 2011; Provencher et al., 2009; Brian Wansink & Chandon, 2006; Brian Wansink, Van Ittersum, & Painter, 2004; Wooley, 1972). These findings have been attributed to "Halo" effects - positive attitudes towards an aspect of a stimulus resulting in overall positive evaluation, or overgeneralizations of positivity to other aspects of that stimulus (Nisbett & Wilson, 1977). In the context of believed-healthy foods this results in lowered calorie estimations (Carels et al., 2006), increased intake norms (Chandon & Wansink, 2007), attribution of additional, unmentioned, healthy characteristics to products (Roe et al., 1999) and holistic judgments of products as healthy or unhealthy (Oakes & Slotterback, 2001).

Additionally, expectations can influence eating behaviour and experience. For example sensory expectations and consequently experience are influenced by available information prior to tasting (Kuenzel, Zandstra, Deredy, Blanchette, & Thomas, 2011; Siegrist & Cousin, 2009; Brian Wansink et al., 2007; Brian Wansink, van Ittersum, et

al., 2005; Yeomans et al., 2008). Consumers also have explicit expectations about foods' satiating potential (Brunstrom et al., 2008), which can influence portion-size selection (Brunstrom et al., 2011; Brunstrom & Shakeshaft, 2009). In familiar foods appetite expectations are generated by learned associations between products and actual satiety (Brunstrom, Shakeshaft, et al., 2010), however in novel foods satiety expectations may be driven by external cues such as physical appearance (Hardman, McCrickerd, & Brunstrom, 2011). It is plausible therefore that labels and health information can influence expected and experienced sensory characteristics and appetite of believed novel products.

However sensory properties, which may be experienced in conjunction with label information in the "real world", also provide appetite cues (Bertenshaw et al., 2013; McCrickerd et al., 2012). Expectations are tested against experience and quickly assimilated (ratings move in a direction consistent with the initial expectation) when discrepancies are small or not noticed, whereas if discrepancies are noticed stimuli are systematically analysed and contrast effects (ratings move in the opposite direction to initial expectations) can occur (Klaaren, Hodges, & Wilson, 1994; Wilson, Lisle, Kraft, & Wetzel, 1989; Yeomans et al., 2008; Zellner et al., 2004). This implicates a role for the extent of confirmation of pre-taste expectations by oral experience (and cues) provided by foods' sensory properties in eating experience and behaviour. Existing health information studies (Provencher et al., 2009; Brian Wansink & Chandon, 2006) did not assess ratings differences between pre and post-tasting making it difficult to differentiate effects of prior expectations and oral experience on health halo-type effects. It is therefore unclear whether beliefs about products from pre-taste information generate health halos or whether products' sensory properties override these beliefs in ultimate evaluations and meal decisions.

In the first of two experiments we tested the hypothesis that health information labelled on a beverage would influence the rated healthiness of the beverage after tasting, decrease its expected satiating power and increase intake. We also predicted that the

label would influence ratings of the sensory characteristics. In a second study we explored how these factors were influenced by the congruence between label information and oral experience. We predicted that congruence in a health-label context would lead to assimilation, and thus facilitate the health halo-type factors measured in study one, relative to incongruently and unlabelled beverages.

### 5.3 Results Study 1



*Figure 5.1 Brief outline of Study 1 design and procedure: a between-subjects one-way design (label condition: healthy, indulgent, no information).*

Outliers classed as two standard deviations above or below the mean intake of the beverage within condition groups were excluded from analyses ( $n = 4$ ). Two participants were excluded due to a computer error. Analyses were performed on 60 participants. Three Factor Eating Questionnaire (TFEQ; Stunkard & Messick, 1985) dietary restraint and disinhibition and Body Mass Index (BMI) were non-significant as covariates on all analyses.

#### 5.3.1 Baseline ratings

At baseline there were no condition differences in rated hunger, thirst, or desire to eat (all  $p > .079$ ). There was an unexpected effect of condition on baseline fullness,  $F(2, 57) = 3.84$ ,  $p = .027$ ,  $\eta_p^2 = .119$ , which was higher in the control condition than the

indulgent condition, ( $p = .045$ ), although the other conditions did not differ significantly (both  $p > .072$ , Table 5.1). However, although baseline fullness was subsequently entered as a covariate in analyses, it was not found to co-vary significantly on any analysis.

*Table 5.1 -Baseline VAS appetite ratings (+/- SEM) \*significant effect of condition  $p = .027$ .*

	Hunger	Fullness*	Desire to Eat	Thirst
Healthy	41.6 (4.6)	45.2 (4.5)	43.4 (4.6)	56.7 (4.3)
Indulgent	39.7 (5.5)	31.6 (4.1)	47.5 (4.7)	57.8 (3.7)
Control	54.1 (4.4)	30.7 (3.8)	55.7 (3.9)	51.4 (4.8)

### 5.3.2 Healthiness and indulgence ratings

The labels generated appropriate healthiness or indulgent beliefs but tasting overrode initial impressions, shown by convergence towards the control ratings. However label effects on indulgent impressions persisted after tasting (Figure 5.2 A and B). This was supported by significant main effects of condition,  $F(2, 57) = 3.98, p = .024, \eta_p^2 = .12$ , and rating time on healthiness ratings,  $F(1, 57) = 4.98, p = .03, \eta_p^2 = .08$ , and an interaction,  $F(2, 57) = 10.32, p < .001, \eta_p^2 = .01$ . Before tasting the healthy group rated the beverage as healthier than the indulgent and control groups,  $t(29.0) = 3.94, p = .002, t(38) = 2.60, p = .015$ , respectively, and healthiness ratings trended towards being lower in the indulgent than control condition,  $t(33.46) = 1.87, p = .070$ . After tasting there were no differences between conditions (all  $p > .05$ ), suggesting that impressions converged towards the control group following tasting.



There were also significant main effects of condition,  $F(2, 57) = 13.35, p < .001, \eta_p^2 = .32$ , and rating time,  $F(1, 59) = 9.67, p = .003, \eta_p^2 = .15$ , on indulgent ratings, and an interaction,  $F(2, 57) = 6.99, p = .002, \eta_p^2 = .20$ . Before tasting the indulgent group rated the beverage as more indulgent than the healthy and control groups,  $t(37) = 5.86, p < .001, t(39) = 5.69, p < .001$ , respectively. The healthy and control groups did not differ,  $t(37) = 0.36, p = .722$ . Post-tasting the indulgent group rated the beverage as more indulgent than the healthy group,  $t(35) = 2.30, p = .027$ , but did not differ from the control,  $t(39) = 1.20, p = .238$ . The healthy and control groups did not differ significantly,  $t(38) = 0.94, p = .351$ . These findings suggest some persistence of indulgent label effects to post-tasting.

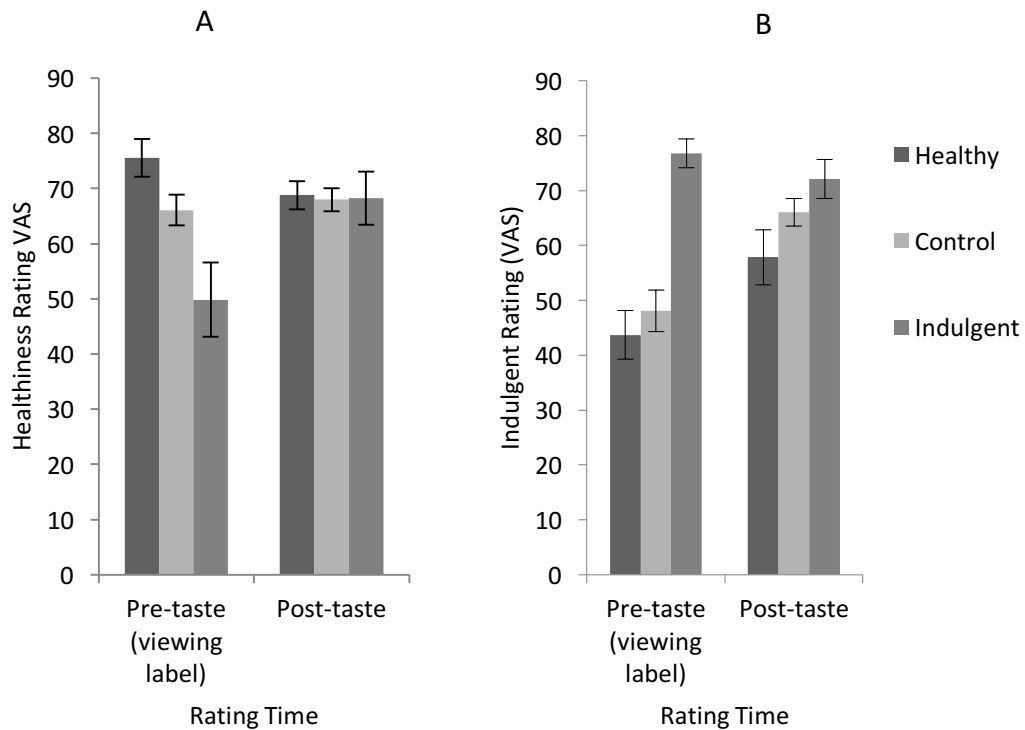


Figure 5.2 Ratings of healthiness (a) and indulgence (b) of a beverage pre and post taste in three different healthiness information contexts ( $\pm 1$  SEM).

### 5.3.3 Expected appetite

There were no significant effects of condition or rating time on appetite expectations (all  $p > .05$ ; Table 5.2).

### 5.3.4 Expected and actual pleasantness and sensory ratings

Expected pleasantness was influenced by label condition but tasting generated convergence with the control (Table 5.2). There were significant effects of condition,  $F(2, 57) = 4.03, p = .022, \eta_p^2 = .13$ , and rating time,  $F(1, 57) = 39.61, p < .001, \eta_p^2 = .41$ , and a significant interaction,  $F(2, 57) = 9.04, p < .001, \eta_p^2 = .24$ . Before the beverage was tasted the healthy and indulgent conditions did not differ,  $t(37) = 0.21, p = .834$ , and both were expected to be more pleasant than the control,  $t(38) = 3.58, p = .001$ , and,  $t(39) = 3.52, p = .001$ , respectively. After tasting there were no differences between conditions (all  $p > .05$ ). Label condition did not influence the sensory experience associated with the beverage (all  $p > .05$ ; Table 5.2).

### 5.3.5 Actual and estimated intake

Unexpectedly actual intake of the beverage did not differ between label conditions ( $p > .05$ , Table 5.3). However, in all conditions intake was over-estimated. The discrepancy was significantly greater than 0 in the indulgent and control groups,  $t(20) = 2.53, p = .020$ ,  $t(21) = 2.57, p = .018$ , respectively. However the healthy group did not differ significantly from 0,  $t(20) = 1.42, p = .170$ , and there was no effect of condition on estimated intake ( $p > .05$ ; Table 5.3).

### 5.3.6 Appetite ratings

After controlling for intake as a covariate there were no differences between groups for hunger, thirst or desire to eat ratings either thirty minutes or sixty minutes following consumption (all  $p > .05$ ; Table 5.3). After thirty minutes there was an effect of

condition on fullness,  $F(2, 59) = 3.69, p = .031, \eta_p^2 = .12$ . Participants in the indulgent condition reported greater fullness than the control ( $p = .011$ ) but the other groups did not differ ( $p > .05$ ).

#### 5.3.7 Summary

Study one found that label information generated healthiness, indulgent and palatability expectations of a beverage but tasting largely overrode these expectations. Indulgent ratings persisted following tasting in the indulgent group compared to the healthy group suggesting partial assimilation. Label information did not influence expected appetite, estimated or actual intake or sensory evaluation. However the indulgent group reported higher fullness ratings after 30 minutes, perhaps related to assimilation of the label information.

Table 5.2 - Pre and post taste VAS sensory and expected appetite ratings (SEM).

Rating Time	Label condition	Pleasant* **	Familiar	Thick	Creamy	Sweet	Expected hungry immediate	Expected hungry later	Expected full immediate	Expected full later
Pre-taste	Healthy	75.4 (3.9)	-				29.8 (4.6)	50.5 (4.3)	70.6 (2.7)	50.7 (4.0)
	Indulgent	54.4 (3.8)					26.8 (3.3)	48.8 (5.1)	67.9 (4.3)	48.6 (5.2)
	No Label	73.8 (3.7)					31.9 (3.9)	52.4 (4.2)	67.6 (3.0)	45.5 (4.3)
Post-taste	Healthy	77.7 (4.7)	73.3 (3.3)	62.9 (4.5)	69.5 (3.1)	75.6 (4.0)	34.2 (4.8)	53.4 (4.7)	66.4 (4.8)	50.2 (4.9)
	Indulgent	81.4 (2.8)	77.0 (4.8)	56.1 (4.7)	68.6 (3.7)	78.3 (3.5)	28.4 (4.8)	51.6 (5.4)	65.8 (3.8)	48.7 (5.5)
	No Label	82.7 (3.3)	71.1 (4.1)	59.6 (4.7)	65.2 (4.0)	75.0 (2.7)	33.1 (4.6)	50.4 (4.3)	67.4 (4.5)	45.5 (4.8)

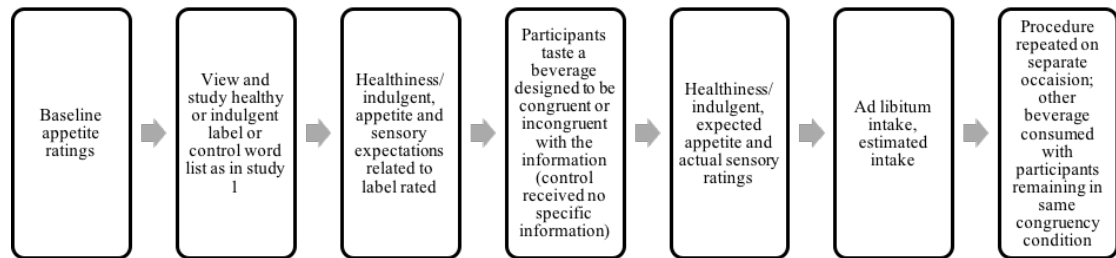
\*Significant difference between rating times ( $p < .001$ ), \*\* significant difference between label groups ( $p = .022$ ).

Table 5.3 - Intake, estimated intake and the discrepancy between the two (kcal) and VAS appetite ratings 30 and 60 minutes following intake by label condition.

	Rating at 30 mins							Rating at 60 mins			
	Intake	Estimated	Discrepancy	Hunger	Fullness**	Desire	Thirst	Hunger	Fullness	Desire	Thirst
Healthy	159.00 (29.56)	195.79 (36.79)	36.79 (14.82)	31.1 (4.4)	63.5 (3.5)	31.5 (5.0)	45.6 (5.6)	37.8 (5.4)	54.3 (4.9)	37.8 (5.7)	46.9 (5.3)
Indulgent	169.52 (26.69)	225.56 (31.41)	56.03 (25.37)*	28.8 (5.4)	65.6 (4.9)	32.6 (5.5)	29.4 (5.5)	36.7 (6.2)	57.3 (5.5)	40.1 (6.7)	35.9 (6.2)
Control	183.03 (27.36)	218.42 (25.19)	35.39 (19.49)*	41.5 (5.7)	55.5 (4.7)	42.0 (5.6)	31.9 (5.0)	42.6 (6.4)	52.1 (6.1)	43.9 (6.0)	33.1 (5.5)

\*Significantly different from 0 ( $p < .020$ ), \*\* significant difference between label conditions ( $p = .031$ )

## 5.4 Results Study 2



*Figure 5.3 Brief outline of Study 2 design and procedure: a mixed three (information condition: congruent, incongruent or no information; between subjects) by two (beverage: actual healthy or actual indulgent; within subjects) design.*

One explanation of the effects found in study one is that consumers form hypotheses from available information that are tested against oral experience. In this case experience refuted some of those hypotheses and confirmed others – that the indulgent-labelled beverage was indeed indulgent, which lead to higher fullness. To explore this further study two tested the hypothesis that label-experience congruence would lead to assimilation of initial impressions and incongruence would lead to contrast. Two products, one overtly healthy and the other overtly indulgent, were combined with the labels congruently and incongruently and the effects on expected and experienced product impressions, appetite and intake were examined (Figure 5.3).

### 5.4.1 Baseline Appetite

There were no differences between the beverages, or conditions on ratings of baseline hunger, fullness, desire to eat or thirst (all  $p > .144$ ; Table 4).

*Table 5.4 - Baseline mean (SEM) VAS appetite ratings by label and beverage conditions.*

Beverage	Label Condition	Hunger	Fullness	Desire to Eat	Thirst
Healthy	Congruent	52.7 (4.4)	35.2 (4.6)	54.8 (4.3)	57.0 (3.2)
	Incongruent	52.8 (5.2)	34.6 (4.1)	57.1 (5.1)	57.5 (4.0)
	No Label	54.6 (4.9)	39.5 (4.8)	58.2 (4.5)	67.8 (2.7)
Indulgent	Congruent	51.4 (5.3)	31.4 (3.7)	50.4 (5.1)	59.2 (4.4)
	Incongruent	54.6 (4.8)	30.0 (5.1)	55.2 (4.8)	63.7 (4.0)
	No Label	54.3 (5.0)	34.8 (4.5)	56.2 (5.4)	64.2 (4.5)

#### 5.4.2 Manipulation check and label ratings

Manipulation check ratings found the healthy label to be healthier than the indulgent label,  $t(51) = 14.33, p < .001$ , and the indulgent label more indulgent than the healthy label,  $t(51) = 9.42, p < .001$ . There were no differences in expectations of product pleasantness,  $t(51) = 0.61, p = .546$ , but based on the healthy label the product was expected to be less thick,  $t(51) = 4.58, p < .001$ , less creamy,  $t(51) = 11.25, p < .001$ , and less sweet,  $t(51) = 5.75, p < .001$ , than the product described by the indulgent label. The healthy label was associated with higher expected hunger and lower expected fullness than the indulgent label. This was confirmed by paired samples  $t$  tests for expected immediate and one hour later hunger ratings,  $t(51) = 2.46, p = .017$ ;  $t(51) = 4.42, p < .001$ , and fullness ratings,  $t(51) = 5.18, p < .001$ ;  $t(51) = 4.34, p < .001$ , respectively (Table 5.5).

### 5.4.3 Healthy and indulgent ratings

The beverages differed in healthiness and indulgence and there were subtle effects of the congruency of the label information (Figure 5.4). This was confirmed by a significant effect of beverage,  $F(1, 75) = 165.31, p < .001, \eta_p^2 = .69$ , with the healthy beverage rated as healthier than the indulgent ( $p < .001$ ). There was no significant main effect of label,  $F(2, 75) = 0.17, p = .844, \eta_p^2 = .01$ , but there was a significant interaction,  $F(2, 75) = 3.99, p = .023, \eta_p^2 = .10$ . There was a borderline significant effect of label on the healthy beverage,  $F(2, 75) = 3.03, p = .054$ , with healthiness rated higher in the congruent than the incongruent condition ( $p = .017$ ) but no other differences between conditions (both  $p > .144$ ). There was no effect of condition for the indulgent beverage,  $F(2, 75) = 1.10, p = .34$ .

Similarly there was a significant effect of beverage on indulgent ratings,  $F(1, 68) = 89.88, p < .001, \eta_p^2 = .55$ , with the indulgent beverage rated more indulgent than the healthy ( $p < .001$ ). The overall effect of label was not significant,  $F(1, 68) = 0.17, p = .68, \eta_p^2 = .003$ , and nor was the interaction,  $F(1, 73) = 0.80, p = .373, \eta_p^2 = .01$ . There was a significant beverage order effect,  $F(1, 68) = 7.78, p = .007, \eta_p^2 = .10$ , which interacted with beverage,  $F(1, 68) = 4.79, p = .032, \eta_p^2 = .07$ . With the healthy beverage first indulgent ratings were higher ( $p = .02$ ), but there was no order effect for the indulgent beverage ( $p = .366$ ).



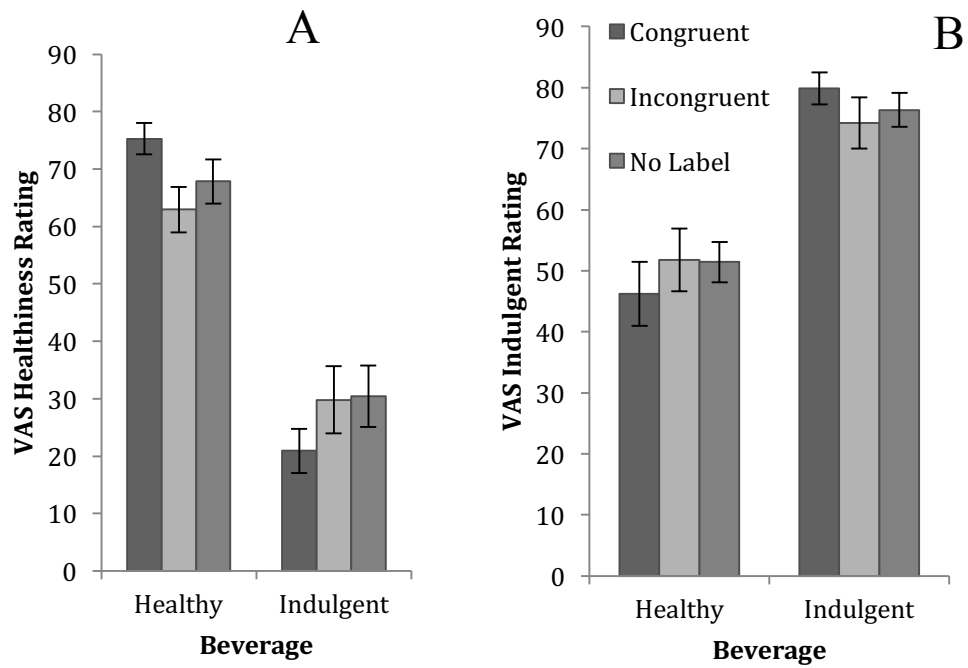


Figure 5.4 Healthy (a) and indulgent (b) ratings of each beverage following congruent, incongruent and no label information ( $\pm 1$  SEM).

Table 5.5 - Mean (SEM) VAS ratings of the labels (Part A) and beverages by label condition (Part B)

Beverage condition	Label condition	Healthy	Indulgent	Pleasant**	Familiar**	Thick**	Creamy**	Sweet**	Expected hungry immediate	Expected hungry later	Expected full immediate	Expected full later
A) Pre-taste – Label ratings	Healthy	80.9 (2.2)*	45.2 (3.5)*	73.5 (2.5)	-	59.3 (3.1)*	30.5 (3.7)*	61.2 (2.2)*	37.1 (3.2)*	57.5 (2.9)*	53.2 (3.5)*	39.7 (3.5)*
	Indulgent	27.0 (3.2)	84.7 (2.5)	75.6 (3.0)	-	78.6 (2.1)	85.6 (2.4)	78.1 (2.2)	26.8 (2.6)	41.3 (3.1)	74.0 (2.7)	58.3 (3.4)
B) Healthy	Congruent	(Figure 5.5a)		62.6 (5.6)	59.0 (5.4)	69.4 (3.2)	43.3 (6.5)	71.1 (4.4)	29.6 (3.8)	45.1 (5.0)	70.3 (3.8)	49.9 (4.4)
	Incongruent			63.2 (6.4)	57.0 (6.0)	71.4 (2.9)	41.6 (6.5)	71.4 (4.2)	35.7 (4.4)	55.1 (4.9)	61.5 (3.3)	46.7 (4.6)
	No Label			61.2 (4.3)	52.1 (5.6)	74.1 (2.1)	41.7 (5.3)	62.2 (4.1)	31.2 (4.2)	49.6 (4.0)	71.0 (3.9)	51.9 (3.9)
Indulgent	Congruent	(Figure 5.5b)		87.1 (2.5)	86.5 (2.4)	44.0 (4.2)	72.8 (3.8)	75.8 (3.5)	30.9 (4.7)	56.2 (4.7)	73.6 (3.8)	53.2 (5.0)
	Incongruent			86.4 (3.7)	83.0 (3.6)	49.2 (5.3)	66.5 (5.4)	81.4 (2.6)	36.0 (5.5)	51.4 (5.3)	68.5 (4.9)	54.9 (5.3)
	No Label			84.6 (2.8)	80.2 (3.7)	53.4 (5.0)	65.3 (4.2)	78.4 (2.0)	27.4 (4.7)	47.6 (4.5)	70.8 (4.6)	48.8 (5.5)

\* Significant difference between label ratings ( $p < .017$ ), \*\*significant difference between beverage conditions ( $p < .001$ ), no effects of label condition (Part B)

#### 5.4.4 Sensory characteristics

There were sensory differences between the beverages, with the healthy beverage rated as less familiar,  $F(1,75) = 55.05, p < .001, \eta_p^2 = .42$ , creamy,  $F(1,75) = 30.21, p < .001, \eta_p^2 = .29$ , sweet,  $F(1,75) = 14.52, p < .001, \eta_p^2 = .16$ , and pleasant,  $F(1,75) = 46.14, p < .001, \eta_p^2 = .38$ , but thicker,  $F(1,75) = 49.01, p < .001, \eta_p^2 = .40$  than the indulgent beverage. There were no significant effects of label (all  $p > .200$ , Table 5.5).

#### 5.4.5 Expected appetite

There were no significant effects of beverage,  $F(1,75) = 0.06, p = .815, \eta_p^2 = .001$ ,  $F(1,75) = 0.42, p = .518, \eta_p^2 = .006$ , or label condition,  $F(2,75) = 0.95, p = .393, \eta_p^2 = .03$ ,  $F(2,75) = 0.33, p = .722, \eta_p^2 = .01$  on ratings of expected immediate or one-hour-later hunger respectively. Similarly there were no significant effects of beverage,  $F(1,75) = 1.65, p = .203, \eta_p^2 = .02$ ,  $F(1,75) = 0.81, p = .370, \eta_p^2 = .01$ , or label condition,  $F(2,75) = 1.20, p = .308, \eta_p^2 = .02$ ,  $F(2,75) = 0.02, p = .978, \eta_p^2 = .001$ , on ratings of expected immediate or one-hour-later fullness respectively (Table 5.5).

#### 5.4.6 Intake

Intake of the indulgent beverage was higher than that of the healthy beverage (Figure 5.5a),  $F(1,75) = 12.84, p < .001, \eta_p^2 = .15$ , but labelling had no significant effect on intake,  $F(2,75) = 0.97, p = .385, \eta_p^2 = .03$ , and there was no interaction,  $F(2,75) = 4.23, p = .018, \eta_p^2 = .10$ . Healthy beverage intake was underestimated (Figure 5.5b), differing from 0 in the congruent ( $t(25) = 4.55, p < .001$ ), incongruent ( $t(25) = 3.90, p = .001$ ) and control groups ( $t(25) = 3.07, p = .005$ ), but not for the indulgent beverage (all  $p > .124$ ). The beverages differed in discrepancy,  $F(1,75) = 27.06, p < .001, \eta_p^2 = .27$ , but not the label groups,  $F(1,75) = 0.42, p = .662, \eta_p^2 = .01$ , and there was no interaction,  $F(1,75) = 1.80, p = .173, \eta_p^2 = .05$ .

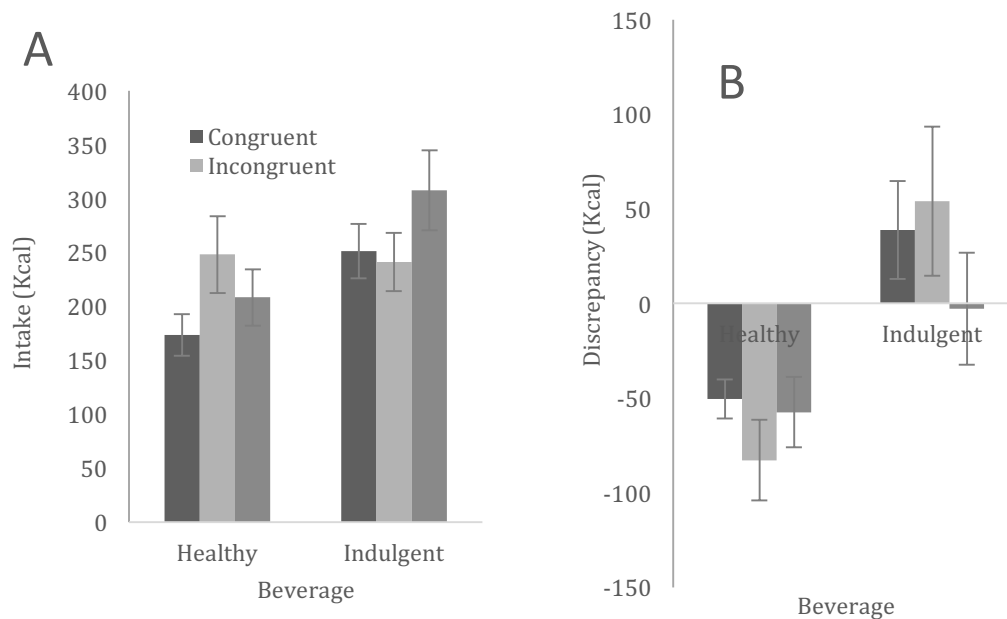


Figure 5.5 A) Intake (Kcal) and B) discrepancy between actual and estimated intake following congruent, incongruent or no label information ( $\pm 1$  SEM).

## 5.5 Discussion

Over two studies we tested the hypotheses that healthy labelling of a beverage would increase healthiness impressions, appetite and intake (and vice versa for indulgent-labelled beverages) and influence sensory ratings. Additionally we hypothesised that label-experience congruency would result in assimilation of healthiness impressions and ultimately enhance health halo effects. We found that whilst the labels themselves were associated with differential healthiness impressions and sensory characteristics, intake and experienced sensory-characteristics were unaffected by labelling or the label-experience congruency. We found subtle evidence of assimilation of label information. Study one found that indulgent impressions were partially assimilated, which increased short-term fullness, supporting evidence that cognitive cues can influence appetite (Cassady et al., 2012; Crum et al., 2011; McCrickerd et al., 2014b). Congruency between the healthy label and oral experience in study two also led to assimilation. One

explanation of assimilation is that minor discrepancies or those that go unnoticed promote rapid evaluation of a stimulus and adoption of consistent elements into the overall evaluation (Kuenzel et al., 2011; T D Wilson et al., 1989; Zellner et al., 2004). This is consistent with the present data given that the congruent conditions likely did not generate large discrepancies between expectations and experience. However, despite this assimilation of healthiness ratings, across two studies we found little evidence of assimilation of pre-taste appetite and sensory expectations associated with the labels.

Incongruence between the label and experience was designed to be extreme in the incongruent conditions, however there was no evidence of contrast effects – incongruently labelled beverages did not differ from unlabelled beverages in healthiness and indulgent ratings despite initial label rating differences. Some studies have reported contrast effects using food stimuli although contrast effects may be rare (Yeomans et al., 2008; Zellner et al., 2004). One possibility preventing contrast effects in the present study is that familiarity with the beverages promoted use of schemas rather than expectations to guide evaluations and behaviour. This is consistent with previous studies demonstrating that the influence of expectation congruency depends on prior knowledge – where detailed prior knowledge was available existing schemas were employed to guide product evaluations and were unaffected by information congruency (Peracchio & Tybout, 1996). Moreover the labels in the present studies were able to generate pre-taste rating differences in expected satiety and sensory properties but not post-taste differences. Thus this supports the idea that these initial differences were overridden by tasting, perhaps suggesting that the sensory properties guided evaluations due to prior knowledge of the product types.

The health halo concept predicts that health beliefs lead to lowered calorie estimations and increased intake norms (Carels et al., 2006; Chandon & Wansink, 2007; Brian Wansink & Chandon, 2006; Brian Wansink et al., 2004). The two studies here suggest that despite assimilation of healthiness impressions intake was influenced little. Study two suggested that healthy-labelling generated lower expected satiety, although neither

label congruency nor oral experience differentiated post-taste expected satiety. There is evidence that appetite expectations may be driven by physical characteristics, such as volume, which could have driven ratings overriding the labels' influence (Brunstrom, Collingwood, et al., 2010). Actual intake was influenced little by label information or congruency, but was greater for the indulgent beverage, despite energy matching. It is likely that this beverage effect was driven by the greater palatability of the indulgent beverage (De Castro, 2001), is thought that health halo effects can occur despite expectation of lowered palatability (Brian Wansink et al., 2004). Additionally high familiarity of the test products may have again overridden the label influences on intake as consumers were able to employ schema-based intake decisions (Peracchio & Tybout, 1996). Overall whilst health beliefs were assimilated intake did not increase.

However, consistent with the health halo idea, intake of the healthy beverage was underestimated. This could be explained as a generalization of healthy-aspects to the whole stimulus (Nisbett & Wilson, 1977) such that experiencing it as healthy resulted in the impression that it was lower in energy content. An alternative explanation is that ordinarily smoothies are relatively less energy dense than presented here (for example the smoothie used here ordinarily delivers 47 kcal/ 100 g). Given that there was no effect of label information on intake estimations it is likely that the estimations were guided by sensory properties and thus previous experience of similar, relatively low energy, beverages. This suggests that label information was overridden by oral experience, perhaps because of high familiarity, in guiding health halo type behaviour.

Previous studies paint a mixed picture of the potential of labels to influence eating behaviour. Several studies have demonstrated that label information can alter sensory and hedonic evaluations, satiation and satiety (Caputo & Mattes, 1993; Crum et al., 2011; McCrickerd et al., 2014b; Provencher et al., 2009; Brian Wansink et al., 2004). However other studies found that labels did not alter the eating experience and that ultimately foods' actual sensory properties and the post-ingestive experience determined product evaluations and appetite (Chambers et al., 2013; Yeomans et al., 2001). The

present data support some subtle label effects on healthiness impressions and appetite but even when the label information generated expectations and was assimilated the ultimate sensory and hedonic evaluations were unaffected by the health labelling and were determined by actual oral experience. This questions the conditions in which label information can influence eating behaviour. As discussed above it is possible that familiarity with the oral stimuli may limit the extent to which expectations and labels are recruited in framing evaluations and behaviour. In which case it may be that familiarity with foods' sensory characteristics promotes use of prior knowledge rather than label influences in determining product evaluations and behaviour.

A limitation of the present study is that whilst we initially separated label believers and non-believers for analysis we did not measure confidence or strength of the expectations that the labels created *per se*. It has been argued that assimilation occurs if expectations are strong, promoting rapid accommodation of expectation-experience consistencies (Klaaren et al., 1994). It is possible, but unclear, that in the present study a lack of confidence in expectations generated by the health information limited the possibility of assimilating appetite or sensory expectations. Indeed it is possible that the context of consuming the product in a laboratory with experimental labels rather than a genuine consumer product with professional marketing may have influenced the confidence in the authenticity of the labels and product, thus affecting the likelihood of assimilation. A further limitation of the study is that it is unclear whether the assimilated healthy and indulgent beliefs and increased fullness represented a change in experience or merely a rating change. It may be that overall evaluation of the products was framed by initial evaluation rather than a change in actual experience (Siegrist & Cousin, 2009).

Given the consistent explanation here that familiarity of the test products could override expectations future studies could manipulate the familiarity of the test products to assess whether this variable interacts with health impressions to mediate the influence of expectations in intake decisions. It is possible that in less familiar products external sources of information may be more likely to influence expectations (Hardman et al.,

2011), and perhaps experience. Additionally other sources of information such as visual and olfactory cues may contribute to product expectations and experience (Shankar, Levitan, & Spence, 2010). Another potential avenue for future research could be to investigate whether these cues are more likely to guide impressions and behaviour than labels in the same way that oral cues did in the present study. Again it is possible that the familiarity of these cues may be a factor mediating whether label information is recruited in decision-making. Finally individual differences in eating behaviour may influence the extent to which external information can modulate appetite experience. Individuals classified as highly restrained may rely more on external cues to assess their appetite experience than those who report low dietary restraint (Ogden & Wardle, 1990). Therefore it may be useful for future studies to assess how dietary restraint status mediates the influence of health impressions on appetite, intake and product impressions.

These findings have implications for marketing healthy products, primarily that honest marketing (or that which matches oral experience) is most likely to influence consumers' evaluations of whether a product is healthy. However in the context of the present findings these impressions are unlikely to alter the oral or post ingestive experience of a familiar product. This could imply that health marketing alone may not be responsible for elevated intake of believed healthy products. It may be difficult to alter the experience of a familiar tasted product through health relevant marketing.

## 5.6 Conclusion

In summary the two studies reported here suggest that beliefs about healthiness and indulgence in beverages can be assimilated when oral-experience is congruent, that assimilated indulgence may enhance short-term fullness, that healthy labels generate decreased expected satiety and that orally-experienced healthy products generate lowered intake estimations. However despite assimilation of healthiness beliefs and clear pre-tasting rating differences there was little evidence of label influences on most



actual appetite ratings, actual sensory characteristics or intake, or post-taste expected satiety. It may be that oral experience of the familiar products dictated these evaluations, rather than labelling or expectations, by recruiting prior knowledge as an evaluation framework.

## 5.7 Study 1 Method

### 5.7.1 Design

A mixed three (label: healthy, indulgent or no information; between subjects) by two (rating time: pre and post-tasting; within subjects) design tested the effect of labelling a beverage as healthy, indulgent or providing no explicit information on expected and experienced satiation and satiety expectations, and healthiness impressions. Subsequent intake, estimated intake, sensory characteristics and actual appetite were compared between label conditions.

### 5.7.2 Participants

A power calculation based on data from Provencher and colleagues (Provencher et al., 2009) who reported an effect size of  $d = 0.46$  for intake between label conditions suggested a sample size of  $n = 63$  with  $\alpha = .05$  and power of .9. Females ( $n = 66$ ) were recruited for a study investigating consumer perceptions and memory. Exclusion criteria were: self-reported BMI  $\geq 30$  or  $\leq 18$ , smokers of  $>5$  cigarettes per week, pregnant or lactating women, those taking prescription medicine other than the contraceptive pill, diabetes, eating disorders or other gastro-intestinal disorders, allergies or aversions to fruit smoothies, those taking part in ingestive behaviour studies at the University of Sussex or who had taken part in an earlier pilot study with the test products. Participants were randomly assigned to label conditions.

### 5.7.3 Materials

#### 5.7.3.1 Visual Analogue Scale ratings

Participants rated their appetite, expected appetite, the beverage's sensory characteristics and their impressions of the beverage's healthiness using computerised 100 pt. visual analogue scales (VAS) (Hill et al., 1984), presented using the Sussex Ingestion Pattern Monitor software (SIPM; Yeomans, 2000). Appetite ratings were presented in the format: "How <rating> do you feel?" anchored with "not at all" and "extremely". The ratings were: hungry, full, thirsty and desire to eat (presented as "how much of a desire to eat do you feel?"). Expected immediate and one-hour-later appetite ratings (hungry and full) were presented as: "How <rating> would you expect to feel immediately/one hour after consuming a bottle the size of the one in front of you?" respectively, anchored as above. The sensory, expected and actual pleasantness and healthiness impressions ratings were presented as "How <rating> is the beverage/ would you expect a beverage with this label to be?" respectively, anchored as above. The ratings were pleasant, familiar, creamy, fruity, sweet, thick, healthy and indulgent.

#### 5.7.3.2 Labels

The study needed to use product labels that were believable as either healthy or indulgent products. Initially, twelve potential labels (six healthy, six indulgent) were designed, varying in wording name and layout. In a pilot study, female volunteer participants ( $n = 12$ ) ordered these labels from healthiest to most indulgent and the most often ranked at either extreme were selected for use in the main study (Figure 5.6 A and B).



Figure 5.6 selected healthy (a) and indulgent (b) labels.

### 5.7.3.3 Beverages

To identify a product that met the study criteria, a pilot was conducted with four commercially available smoothies (all Sainsbury's Plc. UK) which were each rated twice, by volunteer female participants ( $n=12$ ) using VAS for indulgence, healthiness, pleasantness, familiarity, novelty, creaminess and thickness. Of these products, the Strawberry and Banana Smoothie was selected as believably healthy or indulgent (ratings did not differ from 50, all  $p > .05$ , Table 5.6).

*Table 5.6 - Mean (SEM) ratings of piloted beverage characteristics. Beverages: 1) Mango Passion Fruit and Goji Berry Smoothie, 2) Strawberry and Banana Smoothie, 3) Pineapple Banana and Coconut Smoothie, 4) Orange Mango and Passion Fruit (all Sainsbury's Plc. UK).*

	Beverage	Healthy	Indulgent	Pleasant	Familiar	Novel	Creamy	Thick
Taste	1	57.5	50.3 (8.2)	74.6	76.9 (4.7)	21.4	41.2	53.0
1		(8.5)		(3.6)		(6.5)	(9.3)	(8.6)
	2	53.8	51.3 (8.3)	57.1	44.2 (10.7)	54.3	58.4	66.2
		(6.3)		(8.4)		(10.8)	(9.0)	(7.6)
	3	44.6	65.4 (5.1)	66.9	61.4 (7.6)	43.5	67.3	70.8
		(6.2)		(7.7)		(8.4)	(7.8)	(3.4)
	4	52.3	47.5 (9.2)	67.5	50.6 (9.8)	43.4	56.0	70.5
		(7.9)		(5.6)		(9.4)	(7.4)	(5.3)
Taste	1	47.3	54.7 (9.1)	74.1	74.8 (4.4)	24.7	41.8	54.3
2		(8.0)		(7.4)		(8.1)	(7.9)	(7.1)
	2	51.5	54.1 (7.8)	48.8	50.9 (8.5)	43.3	51.1	82.2
		(5.9)		(8.1)		(10.1)	(11.1)	(4.4)
	3	41.7	70.9 (8.7)	66.9	59.3 (8.9)	47.9	73.9	69.3
		(8.4)		(8.8)		(8.6)	(5.4)	(7.5)
	4	58.6	49.3 (10.1)	71.7	63.9 (8.8)	38.7	61.9	65.9
		(7.5)		(5.2)		(8.2)	(6.8)	(6.8)

#### 5.7.3.4 Beverage and label

Finally, to ensure that the combination of the selected labels and beverage were rated appropriately in terms of healthiness and indulgence, a third pilot study was conducted. Participants ( $n = 12$ ) were divided randomly into healthy and indulgent label groups to taste the beverage. The healthy group rated the beverage as healthier than the indulgent group (healthy  $M = 74.0$ ,  $SEM = 11.2$ , indulgent  $M = 51.3$ ,  $SEM = 7.0$ , although not significant,  $p > .05$ ). Unexpectedly the healthy group ( $M = 70.2$ ,  $SEM = 7.0$ ) rated the beverage as more indulgent than did the indulgent group ( $M = 48.7$ ,  $SEM = 4.1$ ,  $p = .024$ ). The original beverage was therefore deemed inappropriate for the study as it was perceived as too indulgent even when labelled as healthy. A secondary test with

separate participants ( $n = 10$ ) was conducted using a second drink, the Pineapple, Banana and Coconut Smoothie (originally neutral in healthiness and novelty but comparatively indulgent, Table 5.6). This beverage with the healthy label was rated as healthier ( $M = 81.2$ ,  $SEM = 3.9$ ) than with the indulgent label ( $M = 56.4$ ,  $SEM = 12.2$ ), and was rated as more indulgent with the relevant label ( $M = 72.8$ ,  $SEM = 14.1$ ) than with the healthy label ( $M = 62.8$ ,  $SEM = 5.3$ ). This beverage was selected as believably healthy or indulgent. The chosen beverage delivered 68Kcal, 0.5g protein, 12.7g carbohydrates, and 1.6g fat per 100g.

#### 5.7.3.5 Control materials

A word list of 28 food-unrelated words (Appendix A) was presented to the control group to control for the time taken between commencing the study and being presented with the beverage, as well as providing material for the false memory-test detailed below.

#### 5.7.4 Procedure

Participants attended the laboratory between 10.30hrs and 13.00hrs having fasted for 2 hours prior, aware that the procedure lasted for 90 minutes and that intake other than the test product was prohibited.

Participants completed baseline VAS appetite ratings before two minutes of studying the assigned label or the control word list. Participants were also provided with an example of the beverage in a 250ml reference bottle. The label groups were reminded that the information was prototype marketing material for a new product and recall would be tested and the control group were told that the word list was for a later recall test and that the bottle would be required for answering subsequent questions about beverages.

Participants then completed VAS expected appetite, sensory and healthiness impressions ratings (see above). A 20g sample of the beverage was provided for tasting and further expected appetite, sensory, and healthiness ratings were completed. An 800g opaque jug of the beverage and a transparent 300ml glass were then provided and participants were instructed to serve and consume as much or as little as they would like, and were told that more was available on request. VAS appetite ratings were completed and participants estimated their intake (Kcal), with reference to information that an equal glass-full amount of orange juice contained 120 kcal.

Participants then waited in the laboratory for sixty minutes completing VAS appetite ratings at thirty-minute intervals before a free recall test was administered to uphold the cover story. Finally participants completed questions assessing whether they believed the label manipulation, height and weight were recorded and they were fully debriefed.

Ethical approval to run the study was granted by the University of Sussex Life Sciences and Psychology Research Ethics Committee. Informed consent was gained for participation and use of data.

#### 5.7.5 Analysis

Mixed three by two analyses of variance (ANOVAs) were used to contrast the label conditions (between subjects) and pre and post-taste rating times (within subjects) on impressions of healthiness, expected appetite, and expected and actual sensory characteristics. One-way ANOVAs assessed the effect of label condition on intake, estimated intake and the discrepancy between the two. The discrepancy was also compared to 0 (being perfect estimation). Finally one-way ANOVAs were conducted on post intake appetite ratings by label condition, controlling for intake as a covariate. All analyses were conducted on the whole dataset as well as splitting believers and non-believers ( $n = 11$ ). This was found to have no effect so the results reported contain the entire dataset.

## 5.8 Study 2 method

### 5.8.1 Design

A mixed three (congruency condition: congruent, incongruent or no information; between participants) by two (beverage received: healthy or indulgent; within participants) design explored the effect of label congruency on product impressions, expected and experienced appetite, sensory characteristics and intake. As in study one labels were presented with a beverage for rating and subsequent tasting and *ad libitum* intake. Study two's manipulation differed in that two beverages were consumed, one overtly healthy and one overtly indulgent, on different days, combined with either a congruent, incongruent or no label. Participants were randomly assigned to congruent, incongruent and unlabelled-control groups and beverage order was counterbalanced.

### 5.8.2 Participants

Females ( $n = 75$ ) adhering to the same criteria as study one, with the additional requirement that they had not participated in study one, were recruited.

### 5.8.3 Materials

#### 5.8.3.1 VAS ratings

Participants completed identical VAS ratings to study one measuring appetite, expected appetite and the sensory and healthiness profile of the beverages. Study two also introduced evaluations of sensory characteristics associated with the labels using the same VAS format.

### 5.8.3.2 Labels and control word list

The study one labels were used (Figure 5.6) either congruently or incongruently with the beverages and the study one word list was used for a control group.

### 5.8.3.3 Test Products

A pilot taste test was conducted using six equicaloric beverages: three milkshakes and three smoothie beverages (Table 5.7). Participants tasted 30g samples and completed VAS sensory ratings (Table 5.7). Chocolate and caramel milkshakes were significantly lower and higher than 50 on VAS healthiness and indulgence respectively. The chocolate milkshake was significantly higher than 50 in familiarity which was considered an advantage for testing expectations against experience. The milkshake was 37.5g Chocolate and Vanilla Ice Cream (Sainsbury's plc.) and 62.5g Semi-Skimmed Milk (Sainsbury's plc.) per 100g, and delivered 100.4kcal, 13.5g carbohydrates, 3.6g fat and 3.5g protein per 100g. None of the beverages were deemed appropriate as overtly healthy, so a further three beverages were tested on new participants ( $n = 9$ , Table 5.7). The apple, kiwi and lime smoothie was significantly healthier than 50, and was selected as the typical healthy beverage. The beverage contained 84.5g Innocent Apple, Kiwi and Lime Smoothie (Coca Cola Co.), and 15.5g maltodextrin (Cargill, UK) per 100g energy-matched to the milkshake and delivered 100.3kcal, 23.6g carbohydrates, 0.1g fat and 0.3g protein per 100g.



Table 5.7 - Mean (SEM) VAS ratings of piloted beverage characteristics -

Beverages: 1) chocolate and vanilla ice cream milkshake, 2) caramel ice cream milkshake, 3) strawberry ice cream milkshake, 4) Apple Peach and Pear Juice (Sainsbury's Plc. UK), 5) Raspberry and Pomegranate Smoothie (Sainsbury's Plc. UK), 6) Strawberry and Blackberry Smoothie (Sainsbury's Plc. UK), 7) Orange Carrot and Ginger Juice (Sainsbury's Plc. UK), 8) Innocent Apple Kiwi and Lime Smoothie (Coca Cola Co.), 9) Orange and Mango Juice (Sainsbury's Plc. UK). \* $p < .05$ .

		Healthy	Indulgent	Pleasant	Familiar	Novel
Pilot 1	1	9.5 (3.6)*	88.6 (3.6)*	90.1 (4.0)*	86.7 (4.7)*	10.4 (3.8)*
	2	12.9 (3.8)*	79.7 (4.0)*	72.6 (9.1)*	62.8 (8.5)	47.8 (10.5)
	3	54.0 (7.1)	71.5 (8.4)	81.7 (7.8)*	65.9 (7.6)	29.7 (10.2)
	4	56.2 (9.4)	42.5 (8.2)	71.5 (6.8)*	66.1 (9.4)	28.6 (7.1)*
	5	56.9 (10.4)	36.1 (6.5)	59.4 (10.1)	49.2 (10.8)	46.6 (10.3)
	6	57.5 (9.4)	51.6 (5.0)	70.0 (8.2)*	56.6 (10.4)	46.4 (9.0)
Pilot 2	7	46.9 (8.1)	37.1 (7.1)*	58.4 (5.8)	48.1 (6.2)	61.9 (7.0)
	8	68.6 (4.5)*	55.9 (6.2)	81.8 (2.0)*	54.3 (8.3)	56.1 (7.2)
	9	31.2 (7.0)*	43.4 (9.3)	49.4 (7.2)	56.7 (7.1)	37.2 (9.0)

#### 5.8.4 Procedure

The procedure was identical to study one except that the reference bottle was empty. This was because some participants received an incongruent label-beverage combination and the sight of the actual beverage may have generated expectations that challenged the label manipulation.

Ethical approval to run the study was granted by the University of Sussex Life Sciences and Psychology Research Ethics Committee. Informed consent was gained for participation and use of data.

#### 5.8.5 Data Analysis

Three by two ANOVAs compared the effects of label congruency (between participants) and actual beverage (within subjects) on expected appetite, intake, estimated intake and sensory and healthiness impressions. Pre-taste VAS ratings of appetite expectations, healthiness, indulgence and sensory characteristics were analysed as manipulation checks. In study one the beverage was in view and thus expectations could be rated. However here the label was not linked to the product at the point of rating and ratings were considered for the labels rather than expectations of the beverage. For these ratings those who saw the healthy label (congruent healthy and incongruent indulgent) and the indulgent label (congruent indulgent and incongruent healthy) were grouped respectively. Analyses initially included beverage order, BMI and dietary restraint and disinhibition but were removed as non-significant covariates, except where stated. Analyses were run separately with reported believers and non-believers as in study one, but there were no differences so analyses reported here contain the entire dataset.

#### 5.9 Author contributions

PH designed the study with comments from MRY. Materials were generated and data was collected by PH and analysed by PH with comments from MRY. The manuscript was drafted by PH with comments from MRY.

### 5.10 Appendix A – Control Word List

Boot, Brace, Brown, Bulb, Currency, Invoice, Parallelogram, Raven, Russia, Triangle,  
Afterthought, Bus, Cougar, Ethiopia, Gondola, Hardcover, Michelle, Priest, Save,  
Butane, Colt, Cylinder, Fang, Font, Organisation, Spring, Step-mother, Unit

## 6 General discussion

### 6.1 Summary of aims, findings and relationship with literature

This thesis adopted a contemporary approach to appetite control according to which feedback from cognitive and sensory processes modulates homeostatic energy-sensing mechanisms, as outlined in detail in chapter one (e.g. Berthoud, 2006, 2012; Blundell, Hill, & Rogers, 1988; Blundell, Lawton, Cotton, & Macdiarmid, 1996; Blundell & Macdiarmid, 1997; Blundell, 1991). The effects of interactions between orosensory characteristics, representations of foods (e.g. healthiness) and post-ingestive factors on satiation and satiety were of particular interest in the present studies. Previously this framework has led to fruitful attempts to examine how satiety can be enhanced in beverage contexts by providing sensory and cognitive satiety cues, and how satiety cues can lead to rebound effects if insufficient energy is delivered (e.g. Bertenshaw, Lluch, & Yeomans, 2013; Chambers, Ells, & Yeomans, 2013; Hogenkamp, Mars, Stafleu, & de Graaf, 2012; McCrickerd, Chambers, Brunstrom, & Yeomans, 2012; McCrickerd, Chambers, & Yeomans, 2014a, 2014b; Yeomans & Chambers, 2011; Yeomans, McCrickerd, Brunstrom, & Chambers, 2014). The same multimodal appetite control framework also implicates unwanted effects of food representations, such as the over-consumption (and over-generalising of healthy attributes) of foods believed to be healthy (Andrews et al., 1998; Carels et al., 2006; Chandon & Wansink, 2007, 2012; Finkelstein & Fishbach, 2010a; Lee et al., 2013; Oakes & Slotterback, 2001; Provencher et al., 2009; Roe et al., 1999; Schuldt et al., 2012; Schuldt & Schwarz, 2010). The work in this thesis aimed to further explore these consequences of an integrated approach to appetite control, focussing on two broad issues: 1) the extent to which earlier findings regarding sensory-enhanced satiety could benefit consumers, 2) the extent to which expectation matching influences health halo-related satiation effects. The following sections outline the logic, findings and putative explanations of each of the studies. This is a summary of key points and readers are referred to the relevant chapters for exhaustive accounts.

### 6.1.1 Study 1: The effect of energy reductions on sensory enhanced satiety

Study 1 explored satiety responses to various amounts of covertly added energy in sensory-enhanced beverages. The logic behind this question was that whilst in general energy compensation is more accurate for small compared to large covert energy loads (Almiron-Roig et al., 2013) compensation for energy consumed in liquid form is generally poor (Almiron-Roig et al., 2013). Much recent research now supports the idea that by providing orosensory cues such as viscosity and creamy flavours, the satiety generated by energy in liquids can be improved (Bertenshaw et al., 2013; Chambers et al., 2013; Hogenkamp, 2014; McCrickerd et al., 2014b; Yeomans & Chambers, 2011; Yeomans et al., 2014). On the other hand if these sensory cues are present in beverages providing low energy content, rebound effects of higher hunger and subsequent intake may occur (McCrickerd et al., 2014b; Yeomans & Chambers, 2011). A common strategy in existing diet products is to match the sensory profile of minimally caloric products to those of rewarding high-calorie original versions (Yeomans, 2015). In the context of potential rebound effects and minimal satiety without the combination of sensory cues and energy content, this approach is likely to be counterproductive. However the original studies of the enhanced satiety concept used differences of 200kcal between high and low energy conditions, producing enhanced satiety or rebound hunger in sensory enhanced versions respectively (Yeomans & Chambers, 2011). Considering all of the above it remained unclear whether smaller energy additions to beverages would be compensated for accurately when consumed in a sensory enhanced context, as found with solid preloads (Almiron-Roig et al., 2013), or whether this would generate rebound hunger effects (Yeomans & Chambers, 2011). This was a potentially valuable question for the development of high-satiety products.

A preload design was used with beverages containing 75 kcal, 140 kcal, 205 kcal and 270 kcal consumed in an enhanced sensory context, and the highest and lowest energy versions consumed without sensory enhancements. The previously reliable sensory-enhanced satiety effect (see Chambers, McCrickerd, & Yeomans, 2015) was not

replicated by the intake data, energy compensation or appetite ratings. Additionally, a Bayes factor analysis of the outcomes demonstrated that the results tended towards support for the null hypothesis. Additionally, the intermediate-energy preloads did not differ from the high and low energy preloads in the satiety they delivered. One potential insight here however was that the intermediate preloads did not differ significantly from perfect compensatory behaviour. Bayes factors indicated indifferent support for the null hypothesis (that the beverages did *not* differ from 100% compensation) or the hypothesis that that compensation scores differed from 100%. Therefore this result requires further substantiation as it could reflect previous findings of a strong satiating capacity of small energy loads in solid and semi-solid preloads (Almiron-Roig et al., 2013). Additionally, the sensory enhancements generated increased filling ratings after one taste. Whilst this measure is limited as an explicit measure of expected satiety (see chapter 2) the finding is consistent with previous reports that viscosity and creamy flavours are associated with expected satiety (Hogenkamp et al., 2011; McCrickerd et al., 2012, 2015; Yeomans et al., 2014). Overall these findings present an unclear picture of the utility of the enhanced satiety concept in minimally caloric beverages, but there was subtle support for greater satiety expectations for sensory-enhanced beverages, and accurate compensation for small energy loads. One limitation was the lack of non-enhanced control preloads for the intermediate beverages, a design feature which would allow interpretation of the sensory effect independently. Presently the effects with these preloads were compared to high and low energy versions. Therefore it is unclear whether the sensory cues generated enhanced satiety relative to beverages without the cues at these energy levels.

#### 6.1.2 Study 2: Sensory-enhanced beverages and the effects on satiety following repeated consumption at home

Study 2 assessed whether sensory-enhanced satiety persists following repeated exposures in a home-consumer trial, and also assessed consumers' attitudes to the enhanced satiety concept. This study was an important extension of the enhanced satiety

concept as the situation in which foods are consumed can influence affective responses (Cardello et al., 2000; Cardello, 1995; Edwards et al., 2003; King et al., 2004; Meiselman et al., 2000). Additionally factors which may be prominent outside of the controlled laboratory environment such as social influences (Bell & Pliner, 2003; De Castro, 1990), distraction (Brunstrom & Mitchell, 2006; Higgs & Woodward, 2009; Oldham-Cooper et al., 2011) and even ambient lighting and the presence of music (Bellisle et al., 2004) can influence intake. Therefore if the enhanced-satiety concept could be useful to consumers it needed to be explored within a quasi-naturalistic context.

Consumers were provided with shelf-stable, powdered versions of the test beverages and were instructed to prepare (by adding a commercially available juice) and consume them as part of their ordinary routine. Controlled satiety testing was conducted either side of this exposure period. The study found evidence for sensory-enhanced satiety before and after the exposure period, indicated by decreased intake at both testing points. This enhanced satiety effect was further supported by decreased subjective appetite ratings associated with the enhanced high-energy preload, both before and after the exposure period. Unexpectedly there were no differences between the beverages on expected satiation or satiety, and no effects of exposure. Additionally the enhanced sensory beverage was found to be less pleasant than the other beverages.

This study also used two exploratory focus groups to assess consumers' attitudes to the enhanced satiety concept. Key findings from these discussions included that consumers considered substance and thickness to be key attributes of filling products (specifically as thickness makes a beverage more food-like), to a greater extent than caloric content. This is consistent with experimental data on the satiating capacity of viscous beverages (e.g Bertenshaw et al., 2013; McCrickerd et al., 2012, 2014a, 2015; Zijlstra, Mars, de Wijk, Westerterp-Plantenga, & de Graaf, 2008) and those made to appear more food-like (McCrickerd et al., 2014b). Interestingly the participants also noted that healthy snacks can be considered filling, depending on the portion size. In terms of

acceptability, focus group participants confirmed the experimental findings that thickness is linked to lower pleasantness. Additionally the focus groups treated satiety claims with suspicion, in particular being wary of artificial additives used to generate viscosity, a factor which could limit the acceptability of such a product (Cardello, 2003). The consumers also noted the groups most likely to benefit from the enhanced satiety concept were those time-limited consumers requiring a quick, filling snack, and consumers who are concerned with dieting. Finally the consumers suggested that healthy snacking is a growing trend that will be useful in the future.

#### 6.1.3 Study 3: The effect of dietary restraint and disinhibition on sensory-enhanced satiety

Study 3 further explored how the satiety concept can be applied to consumers by assessing its utility in participants who vary in their attempts to restrict their intake. This followed from the exploratory analysis in study 2 which suggested that such individuals, along with time-limited consumers may be most likely to benefit from the enhanced satiety concept. However it was predicted that variations in restraint and disinhibition may be linked to differential response to the sensory-enhanced preloads. This prediction was based on previous research suggesting that those high in restraint and disinhibition may respond to a challenge to their attempts at intake restriction, or external appetite cues, by overeating (Westenhoefer et al., 1994; Yeomans & Coughlan, 2009; Yeomans et al., 2004). This is particularly pertinent given that the traditional sensory-enhanced preloads are designed to appear high-calorie in order to provide a satiety-relevant cue (Chambers et al., 2013; McCrickerd et al., 2014b; Yeomans & Chambers, 2011; Yeomans et al., 2014), and so may provide a particular challenge to dietary restraint, yet these studies all excluded highly restrained participants. This idea was tested using a preload design, similar to study 1 and 2, where the effects of preload sensory context and energy content were compared across restraint status groups (high restraint, high disinhibition; high restraint, low disinhibition; and low in both) defined using the TFEQ (Stunkard & Messick, 1985).



The results demonstrated that consumers who reported high restraint and disinhibition compensated more accurately for energy consumed in the unenhanced sensory context, a finding counter to that found previously in low restrained participants (Chambers et al., 2013; McCrickerd et al., 2014b; Yeomans & Chambers, 2011; Yeomans et al., 2014). One explanation of this effect could be that the sensory characteristics of the enhanced preload generated a disinhibition effect, attenuating compensation for the enhanced preload. However the strong compensation for the unenhanced preload was driven by both greater intake of the unenhanced low energy preload and reduced intake of the unenhanced high energy preload. Therefore it is unclear whether this was a true disinhibition effect. Nonetheless this provides evidence that highly restrained participants who also have strong tendencies to disinhibit respond more accurately to unenhanced than enhanced preloads. Meanwhile those high in restraint but low in disinhibition and those low in both responded with greater compensation for the enhanced preloads, a finding consistent with the previous literature (Chambers et al., 2013; McCrickerd et al., 2014b; Yeomans & Chambers, 2011; Yeomans et al., 2014). Whilst these effects did not reach significance, closer analysis using a Bayes factor demonstrated a lack of sensitivity in the data, rather than support for the null hypothesis. The failure to reach statistical significance is therefore likely to be due to power issues, particularly in the high restraint, low disinhibition group where participant recruitment was problematic. Whilst previous studies have reliably demonstrated strong compensation effects in low restrained participants (Chambers et al., 2013; McCrickerd et al., 2014b; Yeomans & Chambers, 2011; Yeomans et al., 2014), more research is needed to substantiate the compensatory effects for those high in restraint but low in disinhibition.

Further interesting findings from this study were subtly greater subjective satiety ratings by those low in restraint and disinhibition following preloads, than the high restraint groups. Previous research has demonstrated a greater response by low restrained than high restrained participants to internal appetite cues (Heatherton et al., 1989; Ogden & Wardle, 1990; Yeomans et al., 2004). However differences in the internal validity of the

scales used to measure restraint across these studies (particularly the conflation of restraint and disinhibition concepts by the RS, see chapter 1) make it unclear how restraint and disinhibition interact to influence responses to internal and external cues (Westenhoefer, 1991). Presently the data support a greater subjective satiety response to ingestion of a preload by those low in restraint *and* disinhibition. Additionally, an exploratory analysis of the frequency of respondents to the study recruitment drive found that those who reported high levels of restraint were significantly underrepresented. This has important implications for study recruitment, as discussed below, but also explains the smaller samples from these populations in the present study.

#### 6.1.4 Study 4 & 5: Assimilation of healthy and indulgent impressions from labelling influences fullness but not intake or sensory experience

Study 4 and 5 explored the nature of the health halo effect. This was particularly important given the suggestion from the focus group in study 3 that healthy snacking is likely to be important to consumers. Additionally the focus group suggested that healthy foods can be filling, a finding seemingly at odds with increased intake of believed healthy foods (Chandon & Wansink, 2007; Finkelstein & Fishbach, 2010a; Provencher et al., 2009). Therefore this contention required experimental substantiation. The first of the two studies attempted to address flaws in the previous health halo research, firstly by directly manipulating health-relevant expectations, as opposed to inferring them from restaurant marketing strategies (e.g Chandon & Wansink, 2007), and by including a no information control group so that potential health halo effects could be distinguished from satiety-relevant cues generated by ‘indulgent’ messages (as opposed to Finkelstein & Fishbach, 2010; Provencher et al., 2009). Additionally this study measured consumers’ evaluations prior to and following tasting the products to assess the contributions of prior expectations and sensory experience.

The findings suggested that whilst the label information generated relevant beliefs about the healthiness of the beverages post-tasting ratings converged with the unlabelled control beverage. This suggested that orosensory experience overrode prior expectations in determining evaluations. There was some evidence of assimilation of the indulgent beliefs, suggesting that the beverage was more believable as an indulgent product, explaining the lack of assimilation of healthiness ratings. Interestingly both labels generated greater expected pleasantness than the control. However again these ratings were not assimilated – tasting overrode initial beliefs. The labels did not influence intake, although there were differences in the discrepancy between estimated and actual intake. The indulgent and control groups both overestimated their intake, whilst the healthy group did not. Participants in the indulgent group also experienced greater subsequent fullness, perhaps linked to the assimilation of the label information to the experience.

Based on these findings the follow up study explored the degree to which differences between expectations and experience influence the likelihood of assimilation of health messages, and subsequent effects on appetite, intake and sensory analysis. An overtly healthy and overtly indulgent beverage were consumed by participants who had been given congruent, incongruent or no information about the products.

This study found that based on the label the healthy beverage was expected to be less sweet, thick, and creamy, and to deliver lower satiety. After tasting the healthy beverage was rated as healthier when labelled congruently, suggesting an assimilation effect. However intake, sensory and expectation effects were driven by actual beverage condition rather than by the label information, and following tasting there was no effect of label on appetite expectations. Overall these findings suggest that whilst labels might generate some assimilated expectation effects when congruent with sensory experience, tasting was more likely to dictate evaluations and intake decisions. Intake of the healthy beverage was underestimated in all conditions. This is consistent with the health halo concept (Carels et al., 2006) even if actual intake was not affected. However given the

lack of response to label conditions it suggests again that the orosensory properties of the beverage were important for evaluations, rather than pre-taste information alone.

Overall these two studies suggest that whilst health labels can generate expectations about healthiness, satiety and sensory characteristics, the extent to which these beliefs influence post-taste ratings depends on oral experience of the foods. In particular the degree of congruency between expectations and oral experience may influence the effect of prior expectations on post-taste ratings. Consequently health halo effects might be more likely reflect orosensory characteristics than label-based pre-taste expectations. This idea adds nuance to previous health halo research which has not measured the effect of differences between prior health-relevant beliefs and oral experience (Chandon & Wansink, 2007; Finkelstein & Fishbach, 2010a; Provencher et al., 2009; Brian Wansink & Chandon, 2006).

## 6.2 Broader theoretical context and potential mechanisms

Fundamentally, the enhanced-satiety concept is based on an integrated view of appetite whereby the effect of post ingestive feedback is modulated by cognitive and sensory cues, as represented by the satiety cascade (e.g. Blundell et al., 1988, 1996; Blundell & Macdiarmid, 1997; Blundell, 1991). Most clearly, the present results demonstrated that ingestion of a carbohydrate energy load resulted in decreased subsequent intake (Papers 1-3). In Papers 1 - 3 intake of 270 kcal reduced subsequent intake to a greater degree than intake of 70 kcal. This was nuanced in Paper 1 whereby intermediate energy loads (140 kcal and 205 kcal) reduced intake to a greater degree than the low energy versions, but less than the high energy versions. This supports the well-established hypothesis that the body is equipped to respond to energy challenges from carbohydrates (as outlined in section 1.1.1), and consequently modify appetite and intake (e.g. Blundell, Green, & Burley, 1994; Blundell & Tremblay, 1995; Gray, French, Robinson, & Yeomans, 2002; Yeomans, Gray, & Conyers, 1998). However, despite this response to the covert energy additions, energy compensation (the adjustment in subsequent intake

to account for added preload energy) was rarely found to be accurate in the present studies (with the exception of the intermediate preloads in Paper 1 and of the unenhanced version by high restrained and high disinhibition participants in Paper 3). A recent systematic review found high variability in compensation scores with the variance explained primarily by the time between the preload and test meal, preload form (solid, semi-solid or liquid), and preload energy content (Almiron-Roig et al., 2013). The overall median compensation score in Almiron-Roig and colleagues' review was 62%, although it was only 43% for liquids. Therefore the largely inaccurate compensation in the present studies supports the view that compensation for energy additions consumed in liquid preloads is weak. This has been explained previously by increased rate of intake and therefore shorter oral transit time of liquids, leading to weaker orosensory feedback compared to solid foods or those requiring greater oral processing (de Graaf, 2011, 2012). Additionally this shorter oral exposure has been shown to weaken learned satiation (Mars et al., 2009) suggesting a poorer ability to learn satiating consequences of liquids. Therefore liquids may be associated with poorer satiety and compensatory responses due to weaker orosensory feedback. Whilst this was not explicitly tested in the present studies the incomplete compensatory behaviour in studies 1 and 3 supports these ideas.

The present studies also tentatively support the idea that compensation is more accurate for low energy contents (Almiron-Roig et al., 2013). Whilst the preloads did not differ from each other clearly in study 1 the lower energy preloads were less clearly different from accurate compensatory behaviour. This supports the idea that whilst intake is reduced to a greater degree by large energy loads the extent to which this accounts for the original preload energy is greater for small energy additions.

The key hypothesis explored in studies 1-3 was that satiety-relevant sensory cues are able to improve the weak satiety response to beverages. This effect has been observed reliably with viscosity and creamy flavour cues for energy consumed as carbohydrate and protein (Bertenshaw et al., 2013; Chambers et al., 2013; McCrickerd et al., 2014b;

Yeomans & Chambers, 2011; Yeomans et al., 2014), MSG flavours as a specific cue for protein energy (Masic & Yeomans, 2014), and by presenting beverages as filling using product information (McCrickerd et al., 2014b). The present studies provide mixed support for this hypothesis, with only study 2 clearly demonstrating this effect of perceived thickness and creaminess in high-energy preloads. Meanwhile study 3 found mean differences between preloads which were consistent with this hypothesis (in the low restraint low disinhibition, and high restraint low disinhibition groups) but these effects did not reach significance. This was not found to be evidence against the theory by a Bayes factor however, and most likely reflects power limitations. Study 1 on the other hand was anomalous, finding no differences in intake or appetite consistent with effects of sensory cues. Taken together with previous studies into the enhanced satiety concept (Bertenshaw et al., 2013; Chambers et al., 2013; McCrickerd et al., 2014b; Yeomans & Chambers, 2011; Yeomans et al., 2014) the work in this thesis offers some support for sensory-enhanced satiety.

A putative mechanism for these effects is the interaction between pre and post-ingestive feedback. Pre-ingestive feedback, in the form of CPRs, is represented by physiological responses to the sight, smell, taste and even thought of food which prepare the body for ingestion (Power & Schulkin, 2008; Smeets et al., 2010; Woods, 1991). CPRs rely on learned associations between sensory characteristics and post-ingestive consequences and thus link sensory stimulation to satiety-relevant responses. Given that viscosity and creamy flavours may be reliable predictors of energy content, learned from a young age through experience with breast milk (Picciano, 1998), they may be important cues for satiety. Whilst the present studies did not measure any physiological responses, such mechanisms could underlie the behavioural effects observed here. The present data, along with previous findings discussed above, support the idea that pre-ingestive cues interact with post-ingestive responses to actual energy content delivered to determine the experience of satiety.

An additional perspective on this mechanism is that previously repeated exposures to the beverages have resulted in greater importance of the energy content in determining satiety (Yeomans et al., 2014). This was explained within the framework of flavour-nutrient learning, whereby the sensory properties of a food come to predict its post-ingestive consequences (see Brunstrom, 2007; Yeomans, 2012 for reviews).

Accordingly satiety responses to covert energy can be adjusted appropriately following repeated exposures. However in the present study 2 no such adjustment was observed and the orosensory cues continued to influence satiety following the exposure period. It is plausible that the lack of learning effects in this study could be due to contextual differences between the laboratory and the home environment. Yeomans (2012) has noted the specific and highly controlled conditions in which studies should be designed in order to observe flavour-nutrient learning effects. It is possible therefore that the purposeful lack of control outside of the laboratory could account for the lack of dietary learning. Indeed one study has demonstrated that preference for abstract stimuli rewarded with chocolate was curtailed by the simultaneous performance of a complex counting task (Brunstrom & Higgs, 2002). This implies that attention has a role in learning phenomena, perhaps by influencing contingency awareness (Brunstrom, 2004). It may be that the less controlled environment outside of the laboratory contains greater likelihood of distraction and lower contingency awareness, possibly explaining the differences in learning effects. If so this is an important nuance of sensory-enhanced satiety concept for consumer use.

A further issue informed by this thesis is that the effect of orosensory satiety cues was dependent on individual differences in attitudes to food restriction (Paper 3). Based on these findings it is plausible that the putative interaction between pre and post-ingestive satiety cues described above is further modulated by attempts at executive control over intake. The more accurate compensatory behaviour following the unenhanced preload by restrained participants with a propensity for disinhibition could be explained by a disinhibition effect (Westenhoefer et al., 1994). This explanation is based on the idea that satiety-cues (in this case thickness and creaminess) are designed to predict caloric

delivery in order to maximise conditioned pre-ingestive feedback. However restraint theory suggests that those who attempt to restrict their intake could react to a challenge to that restriction by eating to satiety (Herman & Mack, 1975; Herman & Polivy, 1983). Later conceptions argued that individuals also differ in their propensity for disinhibited eating (Westenhoefer, 1991) and that those scoring high in restraint and disinhibition would be susceptible to such effects (Westenhoefer et al., 1994). The cues for high-caloric content could present such a challenge to restrained eating. The present data partially support this theory, although this group did not over-consume following a low energy version of the beverage with orosensory cues. Nonetheless this is a plausible mechanism for the differential effect of individuals scoring highly on restraint and disinhibition scales of the TFEQ and suggests a further nuance to the sensory-enhanced satiety concept.

Another element of the integrated perspective of appetite control is the influence of cognitive processes mediating meal-based decisions and food representations. For example satiety cues generate explicit expectations about the satiating potential of foods which could dictate portion size decisions (e.g. Brunstrom, 2011, 2014; Fay et al., 2011). The present results demonstrated that information about healthiness could reduce expected satiety, however these did not influence portion size selection and satiation. Additionally following tasting there was no longer an effect of label information on these expectations. Recent studies have noted a stronger effect of sensory cues compared to label-based expectations on satiety responses (Chambers et al., 2013; McCrickerd et al., 2014b). This could be taken as evidence that orosensory experience provides a stronger cue than label effects (although it is worth noting that in study 4 presently higher fullness ratings were generated by indulgent labels). Additionally, it has previously been demonstrated that consumers compare novel products to familiar versions in order to guide evaluations (Tuorila, Meiselman, Bell, Cardello, & Johnson, 1994). It is plausible therefore that orosensory characteristics which can be linked to familiar products generate evaluations and behaviours according to existing schemas without requiring interpretation from label-based expectations (e.g. Peracchio &



Tybout, 1996). The influence of expectations on shifts in subsequent experience is often interpreted by an assimilation-contrast model (Hovland et al., 1957). This model suggests that when discrepancies between expectations and experience are small or not noticed evaluations shift in the direction of the prior expectation, but large, noticeable discrepancies result in shifts in evaluations in the opposite direction from the expectation. Presently, subtle rating shifts towards greater indulgent ratings (study 4) and towards greater healthiness ratings when congruently labelled (study 5) support an assimilation model. One possible mechanism for assimilation effects is that strong expectations and small or unnoticed discrepancies promote rapid, shallow processing of a stimulus (e.g. Kahneman, 2003; Zellner, Strickhouser, & Tornow, 2004) requiring little cognitive effort and thus leading to automatic adoption of the expectation (Geers & Lassiter, 1999). It is possible that for many of the ratings in the present studies expectations from the labels were weak (perhaps due to limited belief in their authenticity in a laboratory context) but those from the orosensory experience were strong. This might have dictated the use of an appropriate schema for guiding evaluations and behaviour based on orosensory characteristics rather than label information.

The specific ability of healthiness expectations to modify product evaluations and intake behaviour was of interest to this thesis. Previous accounts have interpreted such effects as expressions of over-generalised beliefs regarding healthiness (Andrews et al., 1998; Carels et al., 2006; Schuldt et al., 2012; Schuldt & Schwarz, 2010; Brian Wansink & Chandon, 2006; Brian Wansink et al., 2004). The present data support these overgeneralisations through the finding that intake of a healthy beverage was underestimated. However in contrast to previous findings (Finkelstein & Fishbach, 2010b; Provencher et al., 2009) these effects were not dictated by label information. Rather, they were dictated by the actual beverage type, suggesting that the orosensory experience guided these judgements. This again supports the idea that in familiar products, or those which can be related to familiar products (Tuorila, Meiselman, et al., 1994), orosensory properties provide stronger cues than label information. However the

specific conditions in which this is the case merits further investigation, given that the laboratory may not be a context which generates strong beliefs in the authenticity of the labels. Nonetheless these intake underestimations could also be explained by the adoption of heuristic processing (Kahneman, 2003) as result of activation of appropriate schemas following the ‘healthy’ orosensory experience. For example even though the products were energy-matched participants may have used a schema which associated healthy products with low caloric content, despite inadequate information to make this judgement accurately based solely on the orosensory experience of the product. This heuristic processing offers an explanation for over-generalised healthy beliefs, activated in this case by orosensory experience rather than label information.

Overall the studies in this thesis support an integrated approach to appetite control whereby orosensory cues can modulate nutrient-generated satiety responses when consumed in a real-world context, although the effects may be influenced by individual differences in restraint and disinhibition. Orosensory cues also exert a strong influence on cognitive processes involved in meal decisions and evaluations, such as overgeneralised healthy beliefs related to ‘healthy’ orosensory experience. Congruency of these cues with prior label information can lead to assimilation of expectations, although ultimately the orosensory experience may be more important in guiding food representations and appropriate intake behaviour. It is plausible that the strength of expectations generated by label information could influence the degree to which orosensory cues override label effects.

### 6.3 Implications of findings for consumers

One key aim of the present studies was to assess whether the enhanced satiety concept could be translated to genuine consumer benefits, and the extent to which health halos might be pitfalls for consumers navigating a food environment with an abundance of health-relevant advice. The implications of the present findings in a consumer context are discussed next.

### 6.3.1 Implications for enhanced-satiety product development and use

The findings from the present studies 1-3 could be used to inform the design of satiety-enhancing beverage products. Although in general the findings provided mixed support for the effects of sensory enhancements there were some nuances to previous findings that could be valuable insights into effective product development. Firstly, it is possible that intermediate energy loads (currently tested between 140 kcal – 205 kcal) may generate accurate compensation. This is based on finding no clear difference from perfect compensation presently in study 1, whilst high-energy equivalents generated clearly sub-optimal compensation. Overall the results of this study did not provide a clear picture of enhanced-satiety, and when compared between preloads there was no clear difference in compensatory response. Therefore, the findings should be treated with caution and a need for further substantiation. However, a recent systematic review demonstrated that compensation for solid and semi-solid preloads was greater for smaller energy loads (Almiron-Roig et al., 2013). Whilst the present research did not find a clearly stronger compensatory response for the smaller energy loads, these were less clearly different to perfect compensation. Thus this may indicate that when consumed in a sensory-enhanced context, small energy loads provide strong compensation in beverages too. Yeomans (2015) has noted that a common strategy for developing diet products is to match the sensory profile of minimally caloric products to rewarding, high-energy equivalents. This has previously been considered counter-productive due to rebound effects (McCrickerd et al., 2014b; Yeomans & Chambers, 2011). However the present data support the idea that strong compensation can be achieved in beverage products with intermediate energy contents. Therefore small energy additions could be considered an improvement to this current strategy. The present thesis considers it a possibility that optimal compensatory behaviour is observed for small energy additions to sensory-enhanced beverages. However this warrants further research to clarify the present unclear findings.

A clearer finding implicating product design and use was that the enhanced satiety concept has utility as a genuine consumer product. Study 2 demonstrated that the sensory enhancements are able to promote satiety in a home-consumer environment over repeated exposures. This is clearly an important step given that the less-controlled environment outside of the laboratory contains many additional cues which could affect intake in the ‘real-world’. For example potential influences on satiety responses that would typically be controlled in a laboratory setting include the presence of other people (Bell & Pliner, 2003; De Castro, 1990), distraction from television and computer games (Brunstrom & Mitchell, 2006; Higgs & Woodward, 2009; Oldham-Cooper et al., 2011), lighting and music (Bellisle et al., 2004). Additionally this study required participants to prepare the test beverages themselves using a powder formulation. One initial concern here was that the powder ingredients would generate expectations that could pre-empt enhanced satiety effects, particularly given that the non-enhanced version contained a very similar volume of powdered ingredients to the enhanced and that perceived volume can influence expected satiety (Brunstrom, Collingwood, et al., 2010). Additionally participants were required to add a commercially available juice to the powder. This particular juice was packaged in a container which claimed low sugar content. This may have countered enhanced satiety effects by generating low-caloric expectations (e.g. Crum, Corbin, Brownell, & Salovey, 2011; Wooley, 1972) or health halo effects (Chandon & Wansink, 2007; Finkelstein & Fishbach, 2010a; Provencher et al., 2009). However enhanced satiety prevailed based on the enhanced sensory profile of the beverage. Thus this study demonstrated that despite the home-consumer environment and a novel formulation of the beverages which required powdered ingredients and preparation by the consumers themselves the enhanced satiety concept may deliver satiety benefits outside of the laboratory. Products can therefore be designed which cater to consumer convenience and still deliver satiety benefits.

On the other hand, study 2 also suggested that artificially thickened beverages are considered less palatable. The study demonstrated convincing evidence that the sensory-enhanced preload was considered less palatable, as indicated by lower VAS

pleasantness ratings and also in the focus group discussions. Consumers here considered the idea of thickened products unpalatable, particularly with reference to the possibility of use with artificial thickening agents. This idea resonates with findings from Cardello (2003) who found that consumers rated products as less acceptable if they were told a novel production method had been used. Therefore the decreased acceptability of beverages with artificial ingredients could partly reflect expectation effects rather than direct sensory effects. However given that VAS pleasantness ratings also indicated lower pleasantness of the enhanced beverages considerable sensory testing may be required to create acceptable products with characteristics that promote satiety and are also palatable. Recent research has demonstrated that reducing the oil droplet size of emulsions, by processing them at a higher rotational shear mixing speed, increased palatability and ratings of creaminess as well as expected fullness (Lett et al., 2016). This demonstrates that manipulating foods' sensory characteristics through processing methods rather than using additives can lead to satiety-relevant effects without compromising palatability. In the context of Cardello's findings that novel food processing technologies are associated with lower palatability (Cardello, 2003) the marketing of the methods used to generate the sensory differences would need to be carefully considered. Additionally, the enhanced satiety concept relates to various cues that promote beliefs that a beverage is satiating. For example McCrickerd demonstrated that framing a beverage as satiating rather than thirst quenching increased satiety responses (McCrickerd et al., 2014b). This finding is supported by growing evidence that framing products as filling without changing actual sensory properties can increase their satiating potential (Capaldi et al., 2006; Crum et al., 2011; Pliner & Zec, 2007), as well as the findings from the present study 4 that assimilated indulgent information lead to greater fullness ratings. Therefore it is possible that manipulating beliefs in this way could also generate enhanced satiety effects without compromising palatability related to viscosity. However it is worth noting that the present studies 4 and 5 as well as previous studies (Chambers et al., 2013; McCrickerd et al., 2014b) suggest that orosensory cues are more effective than label information as satiety cues.

### 6.3.2 Implications for consumer experience

A further implication of the present research regards the way consumers might experience the effects of orosensory and health label induced beliefs. Interestingly there was relatively little evidence in studies 1 and 2 that the different preloads generated differential appetite ratings, however this is most likely related to the unclear intake effects. However in study 2 where there was a clear effect of the sensory enhancement on subsequent intake this was reflected by higher subjective satiety ratings. This suggests that the influence of orosensory cues on satiety is tangible to consumers. This is important, particularly as one benefit of satiety is its ability to reduce hunger-related dysphoria (Hetherington et al., 2013). For consumers for whom this is the primary benefit of satiety it is clearly important that enhanced satiety is expressed not only in reduced intake but also in the subjective sensation of fullness, and the absence of hunger.

Studies 4 and 5 explored the extent to which health-relevant labelling might influence sensory experience of beverages. Neither study found evidence that the health labels could influence sensory experience despite influencing expectations, although this was possibly due to the familiarity of the test products. Labelling did however influence abstract impressions of healthiness and indulgence when congruent with the orosensory experience. This suggests that consumers may experience abstract representations of healthiness more clearly when marketing strategies and product characteristics are congruent.

### 6.3.3 Implications for product marketing

The present findings also have implications for product marketing. One important finding of the present studies is that different groups of consumers are likely to experience the enhanced satiety concept differentially (study 3). This is particularly important given that study 2 found that consumers considered the concept to be useful

for dieters and those with limited time who require a fast, filling snack. Presently it was found that a population of those concerned about their dietary behaviour (attempting to restrict their intake) and with a propensity for disinhibition respond with more accurate compensation to non-enhanced preloads. This has implications for product marketing as it may be counter-productive to market enhanced satiety products to this population. However satiety has further-reaching benefits for consumers than only aiding maintenance of dietary rules, including reducing hunger-related dysphoria (Hetherington et al., 2013). It may perhaps be more fruitful to market enhanced satiety products as alleviating unwanted hunger effects for time-limited consumers, in the context of the present findings. However to the author's knowledge there are no investigations of enhanced satiety in time-limited consumers. There are reasons to believe that time limiting factors could influence enhanced satiety effects. For example higher eating rate is associated with reduced satiety (Hogenkamp et al., 2010; Zijlstra, de Wijk, et al., 2009). Consumers with limited time may be more likely to consume products rapidly and thus experience reduced satiety. Additionally distraction while eating can limit satiety (Brunstrom & Mitchell, 2006; Higgs & Woodward, 2009; Oldham-Cooper et al., 2011). Again this may be more likely in time-limited consumers with multiple tasks to complete (for example whilst getting ready for work, or before a meeting). It is plausible therefore that time-limited consumers could experience satiety differently to those with sufficient time to avoid distraction and prolong eating rate. Whether this would influence sensory-enhanced satiety is unclear but warrants further investigation. Nonetheless, the present work does suggest that it would be problematic to market sensory-enhanced beverages to highly restrained consumers, if those consumers have a propensity to disinhibit.

Additionally the findings from studies 4 and 5 explicitly explored one possible effect of product marketing – health halo effects. Generally these studies demonstrated that marketing materials were able to generate expectations of healthiness, satiety and sensory experience. However there were only subtle effects of the labels on post-taste ratings when experience was congruent. One explanation of these findings was that the

test products were familiar and therefore schemas for appropriate responses based on the sensory properties of the beverages drove evaluations rather than label-based prior expectations. This has two major implications for the role of product marketing. Firstly honest marketing may be more likely to generate desired effects (the products were considered healthier when labelled as such and oral experience was congruent). Meanwhile indulgent products were more filling when labelled and orally experienced as indulgent. In general this supports an assimilation model (Hovland et al., 1957), which may be important for generating enhanced satiety effects, and promoting perceived health benefits of beverages. Secondly, the present findings suggest that it is unlikely that label information is sufficient to generate intake effects or alter sensory experience alone, particularly if the oral experience of the products is familiar (or potentially if label expectations are weak). Therefore it may be possible to market health-benefits of products without risking unwanted overconsumption. More work is needed to establish exactly what oral experience is likely to generate health halo effects as it is likely that a combination of strong label-based health expectations and oral experience could lead to overconsumption.

#### 6.4 Methodological implications

The present studies also hold implications for the methodology of future studies. The introduction to this thesis argued that in order to claim effects of ingestive behaviour studies as existing outside of the laboratory real world participants and contexts should be examined alongside laboratory studies. This contention is consistent with arguments previously made by Meiselman (Meiselman, 1992a, 1992b). The present studies' findings also support this view given that they presented subtly different results to previous laboratory versions. Firstly, study 2 found that enhanced satiety effects endured following repeated exposures in a home-consumer context, whereas previously in the laboratory enhanced satiety has been found to diminish following exposure (Hogenkamp, 2014; Yeomans et al., 2014). Similarly, study 3 investigated previously reliable effects of enhanced satiety with relevant consumers (i.e. those likely to use such



products in the real world). The effects observed here were the reverse of previous enhanced satiety effects (Chambers et al., 2013; McCrickerd et al., 2014b; Yeomans & Chambers, 2011; Yeomans et al., 2014). In general the discrepancies between these laboratory findings with a homogenous group of consumers, and the present findings, support the contention that in order to generalise laboratory findings to the consumer domain careful selection of relevant populations and relevant contexts should be employed. One factor for consideration here is that highly restrained participants may be underrepresented in studies that are open to participants from across the entire range of restraint scores (see Paper 3). Samples which do not attempt to control for restraint are likely to under-represent restrained participants due to unwillingness to engage with food studies.

Additionally a general point for consideration, as discussed throughout, is the identification of appropriate control groups for compensation values when hypothesising interaction effects. Presently we hypothesised that the enhanced sensory characteristics would increase satiety for the high energy beverage and decrease satiety for the low energy beverage. Therefore compensation scores could be expressions of either, or both, of these effects. As such when comparing compensation scores they represent satiety effects relative to preloads of the same sensory profile and comparison to beverages with a different profile is more problematic. For example identical intake following the enhanced and non-enhanced high energy preloads would show enhanced compensation for the enhanced version if intake of the low energy version was increased, as hypothesised. In the present studies compensations values calculated relative to both low energy preloads were provided for comparison. This demonstrated the highly differential effects that can be produced based on which control is used (in particular see study 3). The implication here is that there is no perfect control group to calculate relative compensation scores for enhanced satiety effects, and the scores should be considered with reference to the profile of the food which generated the score.

Finally the findings from studies 4 and 5 show clear differences between pre and post-taste expectations ratings. Many studies of expectation and health-labelling effects do not consider these differences (e.g. Chandon & Wansink, 2007; Provencher et al., 2009; Schuldt et al., 2012; Sörqvist et al., 2015). In such situations it is not clear whether pre-taste information influences the measured experience or behaviour, or whether this is more strongly related to post-taste expectations. It is suggested that to fully understand expectation effects measurements of pre and post-taste expectations should be measured.

## 6.5 General limitations

Specific limitations of each study are outlined in the relevant chapters. Here more general limitations of the present studies are outlined.

The idea that satiety can be enhanced by the presence of orosensory cues is based on the idea that these cues operate by generating expectations and pre-ingestive feedback. One possible limitation relating to testing this theory is that rather than generating pre-ingestive expectations the findings could be explained by post-ingestive effects. Specifically in order to generate viscosity tara gum, a soluble fibre, was added to the beverages. Several studies report a satiating effect of fibre, possibly through slowing gastric emptying rate (Slavin & Green, 2007). However some authors have attributed these findings to perceived increases in viscosity independently of actual fibre content (Juvonen et al., 2009; Vuksan et al., 2009), suggesting an expectation effect consistent with the present hypothesis. Therefore it is unclear whether the small doses of fibre used in the beverages in this thesis could have had a post-ingestive satiety effect independent of orosensory expectation effects. Additionally any independent effect of tara gum would also have influenced responses to the enhanced low-energy preloads. In the present studies which found differential satiety effects between preloads (study 2 and 3) satiety responses were not consistent with decreased intake of thickened low energy

preloads. Therefore if there is a post-ingestive effect of tara gum it is likely to interact with energy content.

A further limitation of the present work is that macronutrient-specific effects were not considered. Much research has explored the differential roles of the macronutrients in generating satiety. For example protein is often considered the most satiating macronutrient (Westerterp-Plantenga & Lejeune, 2005). However presently the enhanced satiety studies used preloads with energy added as carbohydrate (maltodextrin). Previous versions of the sensory-enhanced satiety paradigm have used mixed carbohydrate-protein preloads (Chambers et al., 2013; Yeomans & Chambers, 2011), although the effect has also been demonstrated using carbohydrate-based preloads (McCrickerd et al., 2014b; Yeomans et al., 2014) as in the present studies. One explicit comparison of viscosity and creaminess found equivalent satiety effects in high protein and carbohydrate beverage preloads (Bertenshaw et al., 2013). Therefore it is likely that these sensory characteristics generally enhance satiety across beverages of various nutritional compositions. There is however some evidence that sensory-cued satiety is macronutrient specific, with umami flavours improving satiety for protein-based soup preloads (Masic & Yeomans, 2014). Therefore whilst it is possible that specific sensory characteristics could cue satiety for particular macronutrients, and satiety in general could be stronger for protein-based preloads, the present studies can only support this effect for carbohydrate-based preloads.

Finally, in the final two studies of this thesis the effect of health beliefs, as generated by label information and sensory characteristics, on intake, appetite and sensory evaluations was measured. The results demonstrated some subtle assimilation effects when orosensory experience was congruent with prior beliefs but no effects on intake, appetite or sensory ratings. As discussed earlier, one factor which could influence the degree to which assimilation of expectations is likely is the strength of those expectations and the confidence in them (e.g. Cardello, 1994; Hovland, Harvey, & Sherif, 1957; Klaaren, Hodges, & Wilson, 1994; Zellner et al., 2004). Given that these

studies were conducted in an experimental laboratory with labels created by the researchers (rather than a professional marketing team) the strength and confidence of expectations may have suffered. Meanwhile several studies have demonstrated that the situation and perceived appropriateness of a food for the situation can influence product evaluations (de Graaf et al., 2005; Edwards et al., 2003; Meiselman et al., 2000). Together these ideas suggest that the laboratory may not provide the ideal context for assessing health halo effects. It is suggested that in exploring expectations generated by real-world relevant stimuli such as product labels a naturalistic context may be more appropriate given that it could influence confidence in expectations. In particular for the present studies the laboratory context could have attenuated the effects of expectations. We found that post-taste ratings tended to dictate product evaluations. Whether this findings would be equivalent using a more naturalistic context is unclear.

## 6.6 Future directions

Pertaining to sensory enhanced satiety there are a number of remaining questions, other than those already discussed. Here and elsewhere (Chambers et al., 2015) sensory-enhanced satiety has been explained in part by the role of CPRs. These responses are generated by sensory modalities other than orosensory properties, such as sight, smell and the thought of food (Smeets et al., 2010). Similarly contextual information (i.e. that a beverage is filling rather than thirst-quenching) has been shown to influence satiety (McCrickerd et al., 2014b). Additionally, flavour is represented by converging inputs from multiple sensory and cognitive domains (Auvray & Spence, 2008; Parma, Ghirardello, Tirindelli, & Castiello, 2011; Spence, Levitan, Shankar, & Zampini, 2010; Spence, 2015; Zampini, Sanabria, Phillips, & Spence, 2007; Zampini, Wantling, Phillips, & Spence, 2008), suggesting that people use information from multiple sensory and cognitive domains to represent food stimuli. Together this evidence suggests that it is plausible that cues from multiple sensory modalities, beyond orosensory, could influence the enhanced satiety concept. It would be interesting to explore whether certain visual, olfactory or even auditory stimuli are able to predict satiating

consequences of foods and enhance the satiety delivered. Indeed, dining in the dark, thus removing visual cues, has been shown to reduce satiety (Scheibehenne et al., 2010). Whether specific visual cues contribute to foods' satiating consequences is unclear and warrants investigation.

Conversely the present studies demonstrated the stronger influence of tasting than prior expectations on ratings of product attributes such as healthiness in studies 4 and 5. It would be interesting to see whether specific sensory characteristics are associated with healthiness, in terms of taste and other sensory modalities. The present study 5 found that the healthy label was associated with lower levels of thickness, creaminess and sweetness. It would be interesting to see whether these specific properties are related to assimilation of health-labels and whether this influences health-halo type effects. Additionally it is plausible that stimuli from other sensory modalities could influence the evaluation of healthiness, and therefore the degree of perceived congruency with health information. For example colour may be important in generating representations of foods (see Shankar, Levitan, & Spence, 2010). Whether specific visual cues relate to the perceived healthiness of food products is unclear. This is a further potential avenue for future research which could identify and isolate characteristics from different sensory modalities which provide cues for healthiness, and explore the extent to which these integrate with orosensory experience to generate health halo effects.

## 7 Conclusion

This thesis indicates that consumers can benefit from orosensory satiety cues, even when self-prepared and consumed repeatedly in their own. However diet-concerned consumers may not benefit. This has implications for the development and marketing of satiety-relevant consumer products: it is clear that consumer satiety products could be produced, with some attention to avoiding compromising palatability, although diet-concerned populations may not be an ideal market. Time-limited consumers are a potential target market for enhanced satiety, although the utility of sensory-enhanced

beverages in this population is yet to be studied. The extent of energy delivery required to achieve enhanced satiety effects remains unclear, although there was tentative evidence that smaller energy challenges are associated with greater intake adjustment. This requires clarification but is a potentially useful factor for designing satiating products with minimal caloric challenges. Finally label information which positioned products as healthy was able to generate expectations about healthiness, sensory characteristics and appetite, and this influenced healthiness ratings and appetite (an indulgent beverage was associated with higher fullness) when congruent. However overall these studies suggested that orosensory characteristics are stronger cues for health halo effects and intake decisions. Together these findings suggest strong effects of orosensory properties on appetite control and cognition associated with dietary behaviour, which is potentially useful for the design and marketing of appetite-relevant consumer products.

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