Biopsychological investigation of satiety responsiveness and its implications for appetite control

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Submitted in accordance with the requirements for the degree of

Doctor of Philosophy

The University of Leeds

School of Psychology

June 2020

The candidate confirms that the work submitted is their own, except where work which has formed part of jointly authored publications has been included. The contribution of the candidate and the other authors to this work has been explicitly indicated below.

In addition, the candidate confirms that appropriate credit has been given within the these where reference has been made to the work of others.

Parts of Chapter 6 are based on a study that has been published

Dalton, M., **Hollingworth, S**., Blundell, J & Finlayson, G. (2015) Weak satiety responsiveness is a reliable trait associated with hedonic risk factors for overeating among women. Nutrients, 7, 7421-7436.

Parts of Chapter 7 are based on a study that has been published

Hollingworth, S., Dalton, M., Blundell, J., & Finlayson, G (2019). Evaluation of the influence of almonds on appetite control: satiation, satiety, hedonics and consumer perceptions. *Nutrients*, 11(9), 2030.

Acknowledgements

For Ada Rose.

Abstract

Some individuals exhibit a weak satiety response to food. This may have implications for appetite control and leave individuals susceptible to overconsumption. The current thesis examined the reliability and validity of the satiety quotient (SQ), a measure of satiety responsiveness. In a series of experimental studies SQ was examined in response to different foods and used as a means of identifying individuals with low satiety responsiveness, termed the 'low satiety phenotype'. Using the SQ, normal weight (Chapters 4, 6 and 7) and overweight and obese (Chapter 8) individuals were categorised as either low or high in satiety responsiveness and were characterised by behavioural (energy intake, food choice), psychological (food reward, eating behaviour traits), physiological (body composition, gut peptides) and metabolic (resting metabolic rate) risk factors for overconsumption. Chapter 4 and 6 examined the reliability of the SQ as a measure of satiety responsiveness and investigated behavioural, psychological and metabolic risk factors for overeating in the low satiety phenotype. In Chapter 7, energy intake, food reward and appetite sensations were compared in the low and high satiety phenotype following the consumption of snack foods that differed in satiating potential. Finally, Chapter 8 investigated the relationship between gut hormones and satiety responsiveness. The low satiety phenotype were characterised by impaired capacity to detect appetite sensations and reduced intensity and duration of post-ingestive activity (Chapters 4, 6, 7 and 8). The low satiety phenotype exhibited greater wanting for high fat foods (Chapter 6), lower control over food cravings (Chapter 4), greater disinhibition (Chapter 6) and greater trait anxiety (Chapter 8), as well as greater energy intake across study test days (Chapter 6 and 7). While individuals differed markedly in their subjective expression of postprandial satiety, this difference did not appear to be encoded in changes in any of the single gut peptides measured in this research. The low satiety phenotype did however show a blunted glucose response (Chapter 8). In addition, it was found that the consumption of snack foods high in fibre and protein is one strategy to improve appetite control in the low satiety phenotype (Chapter 7). In summary, the satiety quotient can be used to identify a distinct, reliable low satiety phenotype. The low satiety phenotype appears to be characterised by behavioural, psychological and physiological factors associated with risk over overeating compared to the high satiety phenotype.

Publications and Presentations

Research Articles

Dalton, M., **Hollingworth, S.,** Blundell, J & Finlayson., G. (2015) Weak satiety responsiveness is a reliable trait associated with hedonic risk factors for overeating among women. *Nutrients*, 7, 7421-7436.

Hollingworth, S., Dalton, M., Blundell, J., & Finlayson, G (2019). Evaluation of the influence of almonds on appetite control: satiation, satiety, hedonics and consumer perceptions. *Nutrients*, 11(9), 2030.

Book Chapters

Dalton, M., Gibbons, C., **Hollingworth, S.,** Finlayson, G., & Blundell, J, E. (2016) Appetite Control in Humans: A Psychological Approach. In: Caballero, B., Finglas, P., and Toldra, F. (eds). The Encyclopedia of Food and Health, Vol. 1, pp 234-238. Oxford: Academic Press.

Oral Presentations

Evaluation of the Influence of Different Snack Foods on Appetite Control in the Low Satiety Phenotype. *Presented at British Feeding and Drinking Group, Reading UK, April 2017.*

Postprandial Gut Hormones and Diurnal Appetite in Overweight and Obese Individuals Varying According to Satiety Responsiveness. *Presented at Society for the Study of Ingestive Behaviour, Montreal, Canada, July 2017.*

Poster Presentations

Weak Satiety Responsiveness is a reliable phenotype associated with behavioural and psychological risk factors for overeating and obesity. *Presented at ASO, London, March 15.*

Efficacy of Almonds Consumed as a Mid-Morning Snack on Appetite Control. *Poster presented at European Obesity Summit, Gothenburg, Sweden, June 2016.*

The Impact of Different Snack Foods on Appetite Control in the Low Satiety Phenotype. *Presented at Society for the Study of Ingestive Behaviour, Porto, Portugal, July 2016.*

The Impact of Different Snack foods on Appetite Control in the Low Satiety Phenotype. *Poster Presented at UKCO, Nottingham, UK, September 2016.*

Prizes & Awards

EASO Summer School Travel & Accommodation Award – June 2015

BFDG 17 Annual Conference Travel Grant – March 2017

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Chapter 1 General Introduction

1.1 Overweight and Obesity in the UK: Trends and Implications

The increased prevalence of overweight and obesity presents a major public health concern. In England, recent statistics report that the majority of adults (67%) are now overweight or obese (67% of men; 60% women), with the prevalence of obesity rising from 14.9% to 28% between 1993 and 2018. While the rate of increase has slowed since 2000 the trend is still upwards and currently 28% of adults are obese (Health Survey for England, 2018). Furthermore, by 2050 obesity is predicted to effect 60% of adult men, 50% of adult women and 25% of children (Foresight, 2007). The upward trend in overweight and obesity has implications for both individuals' health and the economy. There are numerous diseases and health problems associated with overweight and obesity including osteoarthritis, hypertension, heart disease, type 2 diabetes, and certain forms of cancer, infertility, respiratory problems, non-alcoholic fatty liver disease and psychological and social problems (Kopelman, 2007). The many acute and chronic health problems associated with overweight and obesity not only negatively impact the individual, through for example a reduced quality of life, but also place a burden on society as a whole. In the UK the cost of healthcare resources that were dedicated to the treatment of overweight and obesity in 2007 were estimated at £4.2 billion and this has been predicted to rise to as much as £9.7 billion by 2050, with wider costs to society estimated to reach £49.9 billion per year (Foresight, 2007). These trends and implications highlight the importance for a better understanding of the contribution and likely interactions between the causal factors of weight gain and obesity. Furthermore, that there is still the need for the development of effective prevention and treatment strategies.

1.2 Causes of Weight Gain and Obesity

Overweight and obesity are the result of energy imbalance; where energy intake exceeds energy expenditure over a sustained period of time. This could be due to increased energy intake or decreased energy expenditure. However, this energy balance explanation is simplistic and does not take into account the multifaceted set of interactions that arise from environmental, behavioural, psychological and social factors that contribute

towards weight gain and obesity. It is generally accepted that environmental changes are largely accountable for the current levels of overweight and obesity, such as an increased availability of foods that are highly palatable, energy dense and relatively inexpensive (Swinburn et al., 2011). It has been suggested that the current food environment exploits individuals vulnerabilities making it easier to overeat. In addition, there has been an decrease in the energy cost of everyday life (Church et al., 2011). Subsequently, becoming overweight or obese can be described as a 'normal response' whereby the homeostatic regulation of appetite and energy balance is challenged by environmental pressures to overeat. What is more, there is an underlying imbalance in the homeostatic control of appetite as while there are strong defence mechanisms in place to protect against substantial loss of body weight; mechanisms to protect against increase in body weight and adiposity are somewhat weak in comparison (Erlanson-Albertsson, 2005). In addition, for certain individuals energy intake is no longer primarily driven by energy need but instead by the rewarding aspect of food. Thus, both homeostatic and hedonic processes determine appetite control and both can contribute to weight gain and obesity.

1.3   Control of Appetite - Homeostatic and Hedonic Systems

It is now well established and accepted that the control of appetite comprises a network of interactions that form a psychobiological system. These include neural, physiological, metabolic, psychological and behavioural elements (Blundell, Finlayson & Halford, 2010). Furthermore, energy balance is determined by how much food and what type of food is consumed, in relation to energy expenditure. The control of appetite therefore can be defined in terms of homeostatic and hedonic systems, which distinguish between drive and direction of food intake (Blundell & Finlayson, 2008). The homeostatic system represents the regulation of food intake that arises from biological need and acts to maintain both the internal environment and stored energy, and has been well characterised. The homeostatic system consists of a feedback network of hunger and satiety signals that influence the initiation and termination of eating (Berthoud & Morrison, 2008). Satiation and satiety are terms commonly used to describe processes that influence eating behaviour and these inhibitory influences have been conceptualised in the 'Satiety Cascade'; which was originally described by Blundell, Rogers and Hill (1987). Satiation and satiety are elements of a highly complex 'system' in which food intake is under the control of alternating stimulatory and inhibitory influences. Satiation can be used to describe the inhibitory processes which bring an eating episode to an end,

whilst satiety, also an inhibitory process, can be defined as the suppression of the motivation to eat, following food consumption, which leads to the inhibition of subsequent energy intake. The expression of satiety involves an interaction arising from numerous elements including the physiological system, psychological state and type of food eaten. Satiety is a gradual process and time course is an important element; the postprandial period can be divided into distinct phases. As depicted by the satiety cascade the consumption of food is followed by a succession of sensory, cognitive, post-ingestive and post-absorptive influences. Initially, sensory characteristics (including smell, taste and texture) of the ingested foods act to inhibit further consumption of foods with similar properties (Guinard & Brun, 1998; Rolls & Rolls 1997). Following the consumption of food cognitive factors act to further inhibit subsequent intake. Expectations about satiety value or energy load affect early satiety. An early study conducted by Wooley (1972) demonstrated the impact of cognitive factors on satiety; establishing that when an individual is led to believe that the food consumed comprises less or more energy than it actually did, the satiety response reflected the individuals' belief rather than the actual energy input. The post-ingestive phase of satiety includes various neural and hormonal signals from the gastrointestinal tract such as gastric distension and hormonal responses. At this stage, the satiating efficiency of any ingested food depends on numerous factors including weight and volume, as well as energy and macronutrient content. Energy density is a key determinant of subsequent energy intake (Rolls, 2000). For instance, a high energy dense food will induce rapid return for both hunger and desire to eat, compared to the same amount of energy in a large volume i.e. low energy dense food. A hierarchy of satiating power is well established within the literature; proteins are considered more satiating than carbohydrates, which in turn are more satiating than fats (Blundell & Macdiarmid, 1997). Combinations of these nutrients can alter both the intensity and duration of satiety. Additionally, the presence of fibre contributes to increasing satiety (Slavin & Green, 2007). Nutritionally distinct foods elicit the release of different patterns of episodic appetite signals, commonly termed satiety peptides. Ghrelin is the only known orexigenic hormone with circulating levels increasing shortly before meals and being supressed postprandially, suggesting that ghrelin is implicated in hunger and meal initiation (Cummings et al., 2001). Satiety signals in the form of peptides are released in response to the consumption of food. For instance, glucagon-like peptide and peptide YY are released into circulation after a meal, and act to reduce hunger and food intake (Batterham et al., 2006; Gibbons et al., 2013). Following this

phase, once nutrients become available to the periphery, post-absorptive signals act to maintain satiety. Tonic appetite signals are representative of stored energy. For instance, leptin signals to the brain, about the status of the body's energy store, result in decreased food intake and increased energy expenditure (Farooqi et al., 2002). In addition, insulin levels decrease during negative energy balance and increase during positive energy balance (Woods, Decke & Vasselli, 1974). It is only following this final phase, which marks the end of the satiety cascade, that hunger signals return to indicate further energy should be acquired and subsequently ingested. The satiety cascade is not a fixed process and there are likely to be inter as well as intra individual differences in satiety responsiveness. While it is well established that satiety is influenced by numerous factors for example energy consumed, macronutrient composition and components designed to affect the satiety signalling systems (Chambers, McCrickerd & Yeomans, 2015). There has been much less research concerning inter-individual differences in satiety.
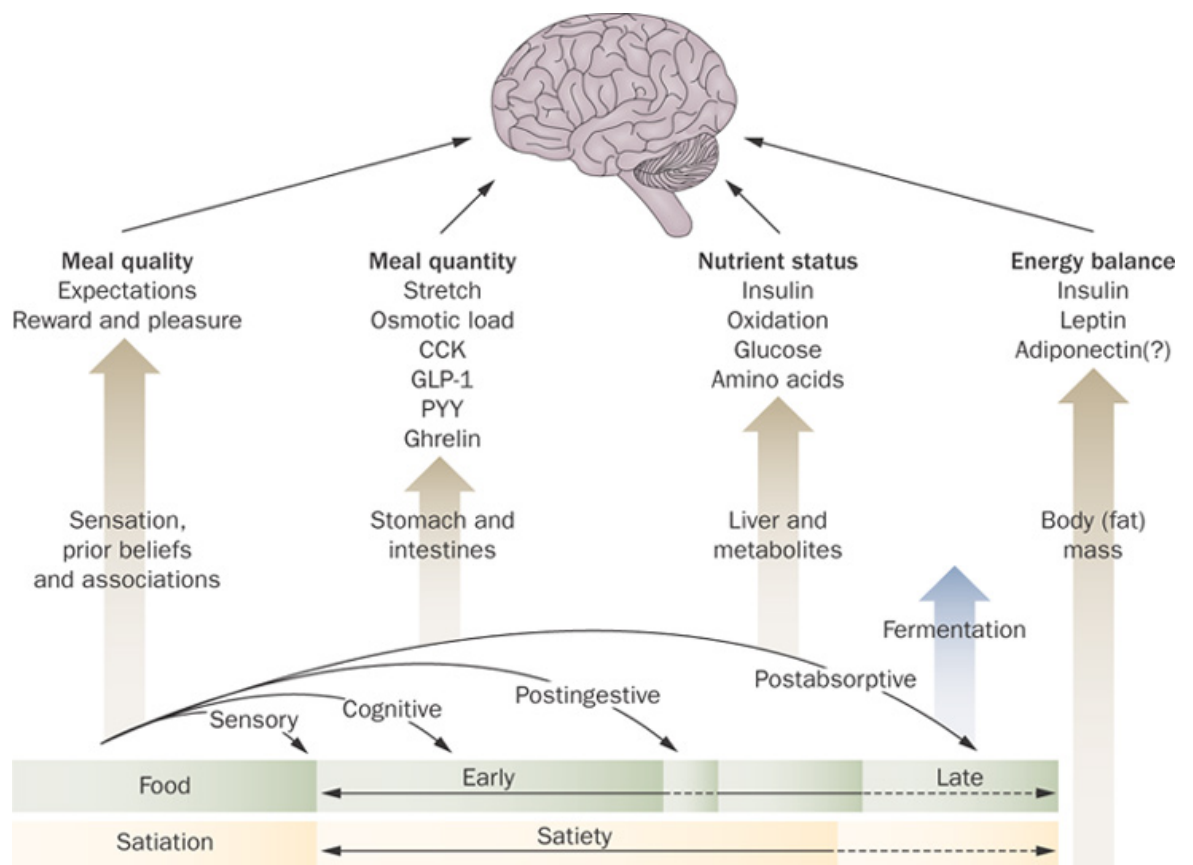
Figure 1.1. The Satiety Cascade, revised by Mela & Blundell (Blundell et al., 2010).

Satiety signals act to reduce the motivation to eat and bring about the termination of an eating episode, however these signals can be altered or even overridden. Whilst investigation of the homeostatic control of appetite and food intake has identified

numerous mechanisms and signalling pathways that contribute towards the control of appetite, it does not describe the entire process. Hedonic influence is equally as important; the hedonic system can override satiety and promote eating. The hedonic system of appetite control represents the sensory and external motivation to eat and takes into account that food intake does not merely arise in response to energy need. It also reflects the current food environment, which is defined by energy-dense, easily available foods that elicit strong reward responses in some individuals. It is thought that the hedonic system of appetite control is underpinned primarily by opioid and dopamine neurotransmission, although other neuro-chemicals have been implicated. Research conducted by Berridge and colleagues has demonstrated that the opioid system mediates the degree of pleasure (liking) derived from food, and the dopamine systems mediates the motivation (wanting) to obtain it (Berridge & Robinson, 2003). In humans liking and wanting for food can be thought of as explicit feelings or subjective states (Finlayson & Dalton, 2012). Liking can be defined as the perceived hedonic impact of a food or appreciation of its sensory properties, whereas wanting describes subjective states of desire or craving. Furthermore, as psychological components of reward, liking and wanting are thought to operate at implicit (automatic) and explicit (voluntary) levels, in a similar to dual process models of motivation (Friese, Hofmann & Wanke, 2008; Wilson, Lindsey & Schooler, 2000). Liking and wanting can be assessed behaviourally in humans using the Leeds Food Preference Questionnaire (LFPQ) which assesses liking and wanting for a selection of food images (Finlayson, King & Blundell, 2008).

The consideration of the interaction between homeostatic and hedonic control of appetite is important in order to fully understand the control of food intake (Finlayson, King & Blundell, 2007). Current evidence regarding the extent to which the homeostatic and hedonic systems of appetite control are distinct or in fact overlap is conflicting. Firstly, some research has demonstrated that the homeostatic and hedonic systems of appetite control are supported by distinct areas of the brain and separate substrates and can therefore be dissociated. For instance, in a sample of obese individuals, suppression of hunger by the serotonin drug dfenfluarmine had no impact on appreciation or pleasantness of food (Blundell & Hill, 1987). Furthermore, Yeomans and Wright (1991) administered either an opioid antagonist (nalmefene) or a placebo to participants who then tasted and rated the palatability of a selection of food items. They established that whilst palatability ratings were significantly lower in the nalmefene condition compared to the placebo condition; there were no differences in ratings of hunger between the two

conditions. However, despite evidence such as this supporting a dissociation between the two systems, some research has established interactions between liking and wanting and hunger and satiety. Research has shown that increased liking of food is able to increase energy intake by increasing hunger and delaying satiation. For example, Rogers and Blundell (1990) demonstrated that consumption of a palatable preload prior to a test meal resulted in a more rapid recovery of hunger compared to when either a bland or no preload was consumed. In addition, Yeomans and colleagues (Yeomans, Gray, Mitchell & True, 1997) examined palatability and ratings of hunger during the consumption of either a palatable or a bland test meal. They found that ratings of hunger increased sharply to begin with and then declined at a slower rate throughout the meal in the palatable food condition compared to the bland food condition. They also found that energy intake was greater in the palatable food condition. Likewise, research has demonstrated that increased levels of fullness cause a decrease in ratings of pleasantness or liking for foods with similar sensory properties (Finlayson, King & Blundell, 2008; Griffioen-Roose, Mars, Finlayson, Blundell & de Graaf, 2010) and also impacts on measures of wanting (Epstein, Truesdale, Paluch & Raynor, 2003; Finlayson, King & Blundell, 2008).

As discussed, the control of human appetite involves complex interactions between physiological, psychological and environmental influences. The current thesis will use a multilevel research platform which incorporates numerous factors involved in appetite control such as environmental, behavioural, psychological, physiological, metabolic and genetic variables. This approach allows the contribution and interaction of different risk factors that may underlie increased susceptibility to overconsumption, weight gain and obesity to be explored. More specifically to the current thesis, it will be used here to investigate the role of satiety responsiveness in susceptibility to overconsumption.

1.4   Susceptibility to Overconsumption and Weight Gain

The current obesogenic environment encourages overconsumption, weight gain and obesity, however, despite this there is a large degree of individual variability in the level of susceptibility to overconsume and gain weight (Blundell et al., 2005). Previous research has demonstrated that it is possible to identify distinct phenotypes, characterised by a specific cluster of characteristics or an underlying genotype, that are susceptible to overconsumption and weight gain (Blundell et al., 2005). A phenotype can be defined as a stable cluster of measurable characteristics that separate one 'type' from another.

Therefore, an approach which utilises behavioural phenotypes may be useful in understanding susceptibility and resistance to overconsumption, weight gain and obesity.

A review of the literature considering underlying mechanisms of eating behaviour in obese phenotypes (Dalton et al., 2013) concluded vulnerability to overeating and obesity may be influenced by risk factors in both homeostatic and hedonic systems of appetite control. Or may even reflect a combination of both. The review highlights the importance of considering individual differences, to gain a greater understanding of factors that characterise phenotypes which are either resistant or susceptible to overconsumption.

Phenotypes can be identified on a number of different levels, with risk factors including genetic, physiological, metabolic, behavioural and psychological influences (Blundell et al., 2005). For instance, obesity as a consequence of a single gene mutation is reasonably rare, with the most common a single gene mutation in the MC4R gene, accounting for approximately 4% of adult obesity (Farooqi et al., 2003). Therefore, it is widely accepted that obesity is under polygenic influence (Hinney, Vogel & Hebebrand, 2010) with genetic susceptibility to weight gain varying amongst individuals according to the number of obesity related risk alleles as well as the profile of allelic variation across a number of different genes. Furthermore, numerous physiological and metabolic factors may increase susceptibility for overconsumption and weight gain including a low basal metabolic rate, low energy cost of physical activity, high insulin sensitivity or insulin resistance and a low fat oxidation (Blundell & Finlayson, 2004). In addition, certain patterns of eating behaviour may enhance susceptibility for overconsumption and weight gain, for instance weak satiety responsiveness, consumption of large meals, frequent eating behaviours and enhanced preference for and consumption of high-fat or energy dense foods (Blundell & Cooling, 2000; Drapeau et al., 2013). Finally, psychological characteristics may also increase susceptibility to overconsume causing weight gain. These include enhanced liking and wanting for food, greater experience of food cravings and certain eating behaviour traits (Blundell & Finlayson, 2004). Using this approach a number of distinct phenotypes at risk of overconsumption, weight gain and obesity have been identified and characterised.

A series of studies by Blundell and colleagues have differentiated between a high-fat and low-fat phenotype based on their habitual fat consumption. These studies demonstrated that high-fat phenotypes have higher baseline levels and quicker recovery of hunger following a meal compared to low fat phenotypes. Furthermore, when provided with ad libitum high fat and high carbohydrate foods, the high-fat phenotype consumed a greater

amount of energy from the high fat foods compared to the low-fat phenotypes who consumed a similar amount of energy from the high fat and high carbohydrate foods (Cooling & Blundell, 1998). In an earlier study Macdiarmid and colleagues (1996) acknowledged that while a greater number of high-fat phenotypes were overweight or obese compared to low-fat phenotypes, there was a large degree of variability in the distribution of BMI in the high fat phenotype. They concluded that while high levels of fat intake were associated with obesity, certain individuals identified as high fat-phenotypes appeared to be resistant to weight gain. The possible mechanisms behind this susceptibility have since been explored (Blundell et al., 2005) with the susceptible phenotypes being characterised by a weaker suppression of hunger following the consumption of high fat foods, strong hedonic responses to high-fat foods when satiated and higher scores on the trait disinhibition and hunger subscales of the TFEQ, which suggested that susceptible high-fat phenotypes might be more prone to opportunistic eating compared to the resistant high-fat phenotype. Finally, the susceptible phenotype described eating more in response to negative affect whereas the restraint phenotype reported eating less. A study conducted by King and colleagues examining the effect of exercise on appetite control and weight loss were able to identify what they termed responders (those who lost the expected weight) and non-responders (those who did not lose the expected weight) (King et al., 2009). When focusing on the whole groups data it was found that medium term exercise prompted a 'dual process' action on appetite. This dual process was characterised by increased hunger levels, but also increased satiety which could compensate for the increased drive to eat. Interestingly, both groups (responders and non-responders) experienced increased satiety, while only the non-responders experienced increased hunger levels. In addition, the responders decreased their energy intake on study test days, while the non-responders actually increased their energy intake. Another behavioural phenotype proposed as a plausible subtype of obesity is the trait or disposition to binge eat (Davis et al., 2009; Hudson et al., 2006). In an initial study it was established that binge eating score, determined using the Binge Eating Scale (Gormally et al., 1982), correlated with BMI, food intake and selection of high fat sweet foods (Finlayson et al., 2011). Additionally, a higher binge eating score was associated with weaker suppression of hunger, greater explicit liking for food generally as well as increased implicit wanting for high fat sweet food. In a follow up study Dalton and colleagues identified and characterised a binge eating phenotype based on scores on the Binge Eating Scale in both lean and overweight/obese individuals. Here the obese binge

phenotype consumed more energy from an ad libitum food task compared to the obese non-binge phenotype and the lean binge and non-binge phenotype. Furthermore, both the obese and lean binge phenotype exhibited greater preference for sweet foods. Finally, the obese non-binge, lean binge and lean non-binge phenotypes demonstrated lower liking and wanting for sweet foods when fed compared to fasted; but this was not the case for the obese binge phenotype who displayed greater wanting for sweet foods when fed compared to fasted (Dalton et al., 2013a). These findings provided additional support for trait binge eating as a hedonic subtype of obesity. Similar characteristics for the phenotype were identified under free-living conditions, which extend the relevance of this particular phenotype to habitual patterns of eating behaviour (Dalton et al., 2013b).

Finally, and of particular interest to this thesis a phenotype of satiety responsiveness has been identified. One potential marker of susceptibility to overeating and obesity is a weakened satiety response to food (Blundell & Gillett 2001). Evidence based on clinical observations suggest some obese patients report a poor relationship between their eating pattern and their sensations of hunger and fullness (Drapeau et al., 2011). This suggests that some individuals may experience an altered or weakened recognition and response to internal signals. Research examining individual differences in satiety responsiveness has demonstrated that obese individuals who report no relationship between their eating behaviour and appetite sensations exhibited a weaker satiety response during a test meal compared to obese individuals who reported that their eating behaviour was related to their appetite sensations (Barkeling et al., 2007). Interestingly, in this study those obese individuals with weak satiety responsiveness had higher scores on the TFEQ subscales of Disinhibition and Hunger compared to controls, and these eating behaviour traits are associated with overconsumption and higher body mass index (Bryant et al., 2008; Blundell et al., 2005). A research group led by Drapeau has conducted a series of experimental studies focusing on individual differences in satiety responsiveness. Their work has provided evidence for individual variability in satiety responsiveness among obese and normal weight individuals (Drapeau et al., 2005; Drapeau et al., 2007; Drapeau et al., 2013). The term 'low satiety phenotype' was first used by Drapeau in 2013. Their research which examines the low satiety phenotype has demonstrated the phenotype is associated with specific behavioural and metabolic profiles (Drapeau et al., 2013).

Identifying and characterising distinct phenotypes of overweight and obese individuals means it is possible to go further than the traditional classification using BMI. In addition it provides potential to contribute towards improved prevention and treatment strategies.

Chapter 2 Literature Review

The focus of the current thesis is satiety responsiveness and its implications for appetite control. Here the current literature regarding the measurement of satiety will be briefly summarised. Studies that assess level of satiety responsiveness to food, in adults, either through the use of the Satiety Quotient (SQ) or the Adult Eating Behaviour Questionnaire will be reviewed. A further aim of this review was to examine whether low satiety responsiveness is associated with impaired appetite control and risk of weight gain.

2.1 Measurement of Satiety

The term satiety is commonly used in the study of appetite control. Satiety describes the period between meals, following the consumption of food, and the processes occurring during this time. The Satiety Cascade (Blundell et al., 1987), which was introduced in Chapter 1, demonstrates two phases of satiety, 'early' and 'late' and recognises the overlapping processes which occur after the consumption food, until the next instance of eating. The assessment of satiety requires a multidimensional approach which takes into account the different aspects of behaviour involved in the expression of satiety. Satiety is most commonly assessed by measuring its subjective level. However, there are other methods commonly used in the measurement of satiety. For instance, not only can satiety be measured through subjective appetite ratings, but also by appetite related peptides and through measures of energy intake (Blundell et al., 2010). These will be discussed here.

The most common method of assessing subjective satiety is visual analogue scales (VAS). Visual analogue scales have been used in both clinical and research settings to measure a range of subjective sensations (Stubbs et al., 2000). Visual analogue scales usually comprise a 100mm horizontal line, anchored at each end by subjective statements (Hill and Blundell 1982). Participants are required to mark along the line to indicate the intensity of a subjective sensation at that point in time, allowing the sensation to be measured and quantified. Sensations typically assessed are hunger, fullness, satiety, desire to eat and prospective consumption. These have been widely used in research for over thirty years. In a recent report Blundell and colleagues (2010) provided suggested wording for both the question and anchor statement to be used. When used to assess subjective appetite, VAS ratings are sensitive to experimental manipulations (Stubbs et

al., 2000) and have shown test-retest reliability (Raben et al., 1995; Stubbs et al., 2000; Flint et al., 2000; Blundell et al., 2010). In addition, it has been shown that the use of visual analogue scales to characterise appetite sensations has good within-subject reliability and validity (Stubbs et al., 2000). The ability of visual analogue scales to predict intake under laboratory conditions is commonly accepted (Holt and Miller., 1995; Stubbs et al., 2000; Drapeau et al., 2007). However, it remains that they are not a valid alternative for measuring actual intake (Blundell et al., 2010). In recent years, there have been a number of investigations into the importance of individual appetite sensations and their associations with actual energy intake. Findings are however inconsistent, with some research identifying hunger as the single best rating (Sadoul et al., 2014) while others have demonstrated that fullness (Drapeau et al., 2005) and desire to eat/prospective consumption (Barkeling et al., 1995) are more closely associated with energy intake. VAS can be administered using pen and paper or on a hand-held Electronic Appetite Rating System (EARS-II, HP iPAQ). The EARS-II has a number of advantages over the traditional pen and paper method, while having similar reproducibility and sensitivity levels to the pen and paper method (Whybrow et al., 2006, Gibbons et al., 2011). Subjective ratings of appetite can also be used in a number of other measures designed to assess satiety for example to calculate Satiety Index (Holt and Miller., 1995) which can be used to quantify and compare the ability of various foods to reduce the motivation to eat, and the Satiety Quotient (Green et al., 1997) which provides a single quantitative value for the satiating power of food, or satiety efficiency of an individual.

Satiety can also be measured through investigating circulating levels of appetite related peptides. Ghrelin, cholecystokinin (CCK), glucagon-like peptide 1 (GLP-1) and peptide YY (PYY) are all thought to play a role in the episodic control of appetite (Gibbons et al 2019). These short term episodic signals, which are released from sites throughout the gastrointestinal tract, fluctuate throughout the day and particularly around meal times. Patterns of these peptides often mirror those of hunger and fullness ratings, therefore they are usually measured simultaneously as indicators or biomarkers of satiety. However, while circulating levels of these appetite related peptides can be used to infer satiety evidence for their exact role remains to be established (Gibbons et al., 2014). For instance, Gibbons and colleagues (2014) have demonstrated that when these peptides are infused in supra-physiological levels, there is evidence for their role in energy intake and appetite control. However, when circulating levels are at a normal physiological amount their influence is less profound. Furthermore, the measurement of these appetite related

peptides is not always straightforward and there are several difficulties in the practicality of measuring appetite related peptides. Firstly, it is essential that standard operating procedures are in place for the measurement of appetite related peptides. Reasons for this include the fact that peptides degrade extremely quickly and samples need to be mixed with inhibitors immediately (dependent on range of peptides to be measured). In addition, studies which include measures of appetite related peptides are expensive to carry out.

Satiety is associated with the period between meals and does not reflect processes that occur during the meal. These processes, known as satiation, bring the meal to an end and therefore determine meal size (energy and/or weight). Whilst energy intake is primarily a measure of satiation the evaluation of satiety by intake remains an important measure.

2.2   Measurement of Satiety Responsiveness

2.2.1   The Satiety Quotient

The measurement of subjective appetite, using visual analogue scales, before and after a standardised test meal, enables the calculation of the satiety quotient; a marker of satiating efficiency. Originally developed by Green and colleagues in 1997, the satiety quotient represents the extent to which consumption of food can alter subjective appetite sensations and is expressed per unit of intake (Green et al., 1997). The satiety quotient can be used to classify individuals according to their satiety signalling capacity, typically a higher satiety quotient represents a stronger appetite response or greater satiety signalling capacity and a lower satiety quotient represents a weaker appetite response or poorer satiety signalling capacity. The satiety quotient can be calculated for hunger, fullness, desire to eat and prospective consumption; as well as for the mean of the four appetite sensations. There is support for the use of the satiety quotient as a method for assessing satiety responsiveness. Furthermore, satiety quotient has been validated in previous research. This review of literature here will look at research in which the satiety quotient has been used to assess participants individual level of satiety responsiveness.

2.2.2   The Adult Eating Behaviour Questionnaire

The Adult Eating Behaviour Questionnaire (AEBQ; Hunot et al., 2016) is a 35-item tool specifically designed to measure appetitive traits including one sub-factor termed satiety responsiveness in adults. The specific items in the AEBQ that make up the factor of satiety responsiveness are 'I often leave food on my plate at the end of the meal', 'I often get full before my meal is finished', 'I get full up easily' and 'I cannot eat a meal if I

have had a snack just before'. The response options included 'strongly agree', 'agree', 'neither agree nor disagree' 'disagree' and 'strongly disagree' The AEBQ was developed based on the Child Eating Behaviour Questionnaire (CEBQ; Wardle et al., 2001) and the Baby Eating Behaviour Questionnaire (BEBQ; Llewellyn et al., 2011). The AEBQ measures eight appetitive traits encompassing both food approach (Hunger, Food Responsiveness, Emotional Overeating, Enjoyment of Food) and avoidance (Satiety Responsiveness, Food Fussiness, Emotional Undereating and Slowness in Eating) appetitive traits. Hunot and colleagues who developed the Adult Eating Behaviour Questionnaire conducted confirmatory factor analysis on the factor structure of the questionnaire in a community sample of 954 adults (Hunot et al., 2016). They reported that the eight factor model showed a good fit to the data. In addition, mean scale scores were correlated with self-reported BMI. Furthermore, as expected the food approach scales, with the exception on Hunger, and the food avoidance scales, with the exception of Food Fussiness, were significantly associated with higher and lower BMI respectively. The Adult Eating Behaviour Questionnaire has since been validated in a sample outside the UK (Mallan et al., 2017). Mallan and colleagues (2017) evaluated the reliability and validity of the Adult Eating Behaviour Questionnaire using confirmatory factor analysis as well as examining the associations with BMI in an Australian sample of 998 participants. Their confirmatory factor analysis results provided support for the eight factor structure of the Adult Eating Behaviour Questionnaire proposed by Hunot and colleagues (2016). Furthermore, correlations between subscales and internal reliability estimates provided further support for use of the questionnaire. Finally, all food avoidance, except for Food Fussiness, were associated with lower BMI and Emotional Overeating was associated with higher BMI. These were consistent with both the hypothesised pattern of associations and the findings of Hunot and colleagues. However, not in agreement with previous findings, in this sample Hunger was negatively associated with BMI and Food Responsiveness and Enjoyment of Food showed no association with BMI. In summary, and of particular importance to the current thesis both studies (Hunot et al., 2016; Mallan et al 2017) reported a negative correlation between BMI and satiety responsiveness; participants with higher BMI values scored lower on the satiety responsiveness scale. Despite the initial development and validation of the Adult Eating Behaviour Questionnaire its use in research since has been somewhat limited. It should be noted that the AEBQ became available for general research use after the experimental work on this thesis was conducted. To date, the convergent validity of the AEBQ as a

measure of satiety responsiveness has not been tested against the gold-standard method using the satiety quotient. Future research should address this gap in the literature.

2.3 The Role of Satiety Responsiveness in Appetite Control

The phenomenon of weakened satiety responsiveness was first acknowledged in a series of laboratory-based studies conducted by Stanley Schachter (1968). Using the preload paradigm Schachter demonstrated that obese participants did not compensate for preloads while lean controls did; leading to the suggestion that the obese individuals had weaker satiety signals or were less sensitive to them. Later, Blundell and colleagues identified a group of obese individuals who were characterised by impaired satiety signals in response to a test meal compared to normal weight controls (Blundell & Gillett, 2001). In addition, research investigating individual differences in satiety responsiveness has demonstrated that obese individuals who report their eating behaviour to be unrelated to their appetite sensations have a weaker satiety response to a test meal (Barkeling et al., 2007). Interestingly, in this study the individuals who believed they had a weaker satiety response exhibited similar patterns of hunger and fullness in controlled laboratory tests compared to obese and normal weight controls. This would suggest that a weakened satiety feeling can occur despite normal satiety signalling mechanisms. Moreover, this group of individuals with weak satiety responsiveness had higher TFEQ Disinhibition and Hunger scores compared to controls. TFEQ Disinhibition and Hunger are eating behaviour traits that are associated with overconsumption, a higher BMI and opportunistic eating (Bryant et al., 2008). Additionally, it is estimated that approximately 10% of obese individuals, who attended a clinical practice seeking advice for weight loss difficulties, express little or no change in appetite sensations in response to a standard test meal. In this setting it is not uncommon to come across individuals who report difficulties in recognising their appetite sensations either before or after a meal (Drapeau et al., 2011). Based on experimental observations such as these it is clear that some individuals express a weaker satiety response following a caloric load and it is reasonable to propose that in certain individuals impaired satiety signals could promote overconsumption and increase the risk of weight gain. This phenomenon has been termed 'the low satiety phenotype'.

Here the role of satiety responsiveness in appetite control will be examined, more specifically whether appetite control (e.g. subjective appetite, energy intake, eating behaviour traits, food choice, food craving and food reward) differs according to

individual levels of satiety responsiveness. Also, whether low satiety responsiveness is associated with higher BMI, adiposity and risk of future weight gain? Studies that assess level of satiety responsiveness to food, in adults, using either the Satiety Quotient or the Adult Eating Behaviour Questionnaire to measure satiety responsiveness are reviewed.

The majority of studies identified measured satiety responsiveness through the use of the Satiety Quotient (Green et al., 1997; Drapeau et al., 2005; Drapeau et al., 2007; Drapeau et al., 2013; McNeil et al., 2014; Dalton et al., 2015; Salama et al., 2016; Arguin et al., 2017; Buckland et al., 2019; Drapeau et al., 2019). The subjective appetite rating used in the calculation of the satiety quotient differed between these studies, as did the period of time over which the satiety quotient was calculated. Some studies calculated SQ for four appetite sensations including hunger, fullness, desire to eat and prospective consumption (Drapeau et al., 2005; Drapeau et al., 2007; Drapeau et al., 2013; McNeil et al., 2014; Salaman et al., 2016; Arguin et al., 2017). Whilst other studies used just one appetite rating. Both Green and colleagues (1997) and Dalton and colleagues (2015) used hunger to calculate satiety quotient, whilst in their study Buckland and colleagues calculated SQ using fullness appetite ratings (Buckland et al., 2019). In addition, some studies also used a mean of the subjective appetite ratings to calculate a Mean SQ score (Drapeau et al., 2013; McNeil et al., 2014; Arguin et al., 2017; Drapeau et al 2019). There was only one study identified which used a method other than the satiety quotient to measure satiety responsiveness (Zuraikat et al., 2018). In this study an Eating Behaviour Questionnaire, similar to the Adult Eating Behaviour Questionnaire (Hunot et al., 2016) was used. The questionnaire was developed by the researchers and assessed three subscales of eating behaviour, including 5 items relating specifically to satiety responsiveness. The Adult Eating Behaviour was developed and validated shortly after the completion of this study.

2.3.1 Satiety Responsiveness and Energy Intake

Using the satiety quotient and a test meal Drapeau and colleagues demonstrated SQ for fullness to be negatively associated with both total energy intake and relative energy intake (total energy intake – metabolic rate) in normal weight, obese and reduced-obese individuals (Drapeau et al., 2005). Therefore, these authors were able to conclude that individuals with low SQ, who experienced almost no change in meal induced fullness, had higher energy intakes. These findings were confirmed in a subsequent study (Drapeau et al., 2007) conducted on a larger more homogenous sample of obese men and women. Here the negative relationship between SQ for fullness and total energy intake proved stronger for women. In addition to these findings, SQ for fullness was negatively

correlated with percentage fat intake in women (Drapeau et al., 2005) which means lower satiety responsiveness is associated with higher preference for fat. However, it is not possible to establish the order in which this occurs. A diet high in fat has been associated with excess energy intake and lower satiating capacity (Lawton et al., 1993), and it therefore could be argued that a habitual high-fat diet can explain lower satiety signalling capacity. On the other hand, an impaired satiety signalling capacity could predispose individuals to overconsumption, and specifically the consumption of high fat foods. Together these findings indicate that individuals characterised as having a low SQ have weaker appetite sensation responses following a meal and could be more vulnerable to overconsumption.

Additional support comes from a study in which the portion size effect was explored. Zuraikat and colleagues (2018) reported that serving larger portions led to increased intake in individuals with lower satiety responsiveness, an effect which was not seen in those with higher scores. Furthermore, satiety responsiveness continued to influence the portion size effect after adjusting for TFEQ subscales. This provides further support for the suggestion that appetite control differs according to level of satiety responsiveness.

2.3.2   Satiety Responsiveness and Eating Behaviour Traits

Numerous studies have identified associations between satiety responsiveness and eating behaviour traits. Firstly, in a study which included only males (Drapeau et al., 2013) there was a trend towards a negative association between SQ and external hunger. Whilst high levels of TFEQ external locus for hunger may indicate a poor awareness of internal physiological state, only a trend was found and there were no other associations with eating behaviour traits. This finding has since been replicated (Drapeau et al., 2019) with individuals identified as being low satiety responders expressing a higher level of external locus for hunger. A recent study conducted by Dalton and colleagues (2015) established that SQ was negatively associated with TFEQ Disinhibition. This eating behaviour trait has previously been associated with overconsumption and weaker changes in appetite sensations in response to a fixed energy test meal (Barkeling et al., 2007). Furthermore, associations between satiety responsiveness and eating behaviour traits remain evident when measured by alternative means i.e. other than the satiety quotient. In their study, Zuraikat and colleagues (2018) reported a significant positive correlation between satiety responsiveness and restraint, as well as a negative correlation with TFEQ Disinhibition and Hunger. Together these findings suggest that eating behaviour traits do differ according to individual levels of satiety responsiveness.

2.3.3 Satiety Responsiveness and Psychological Wellbeing Questionnaires

Moreover, a study conducted by Drapeau and colleagues (2013) demonstrated an association between SQ and both self-reported anxiety and night eating symptoms. Drapeau and colleagues concluded that anxiety may be involved in the vulnerability to overeating in the absence of hunger and this could be part of the behavioural profile of the low satiety phenotype. This suggestion was supported by existing research. For instance, Dallman (2010) reported that at least 40% of individuals increase their energy intake in response to stress. In addition to this, Wardle and colleagues (2000) demonstrated a positive relationship between stress and energy intake. This finding has been confirmed in a more recent study by the same research group. In their study, which included both men and women, SQ was negatively associated with present state anxiety (Drapeau et al., 2019) with individuals with low satiety responsiveness reporting higher present state anxiety.

2.3.4 Satiety Responsiveness and Food Reward

Research which considers hedonic aspects of satiety responsiveness is somewhat limited. Dalton and colleagues (2015) considered hedonic risk factors for overeating in their study of satiety responsiveness in women and found that SQ was negatively associated with greater implicit wanting fat bias. Compared to high satiety responders, those with low satiety responsiveness consistently displayed a greater wanting appeal bias for high fat foods (i.e. they chose high fat foods more frequently and faster than they chose low fat foods). Previous research has demonstrated that increased wanting for high fat foods is associated with behaviours likely to lead to overconsumption (Dalton et al., 2013, Saelens et al., 1996, Finlayson et al., 2009). This finding is the first to suggest that low satiety responsiveness may be characterised by hedonic risk factors for overconsumption.

2.3.5 Satiety Responsiveness and BMI/Adiposity

Whilst Drapeau and colleagues (2005) identified some interesting correlations between SQ and participant characteristics such as body weight, BMI and percentage body fat in their study they were rather inconsistent. More recently, research has reported some interesting findings between satiety responsiveness and BMI and adiposity. For example, the researchers who developed the Adult Eating Behaviour Questionnaire found that adults with a higher BMI had lower scores for food avoidance traits (including satiety responsiveness). This finding is consistent with findings from research in children, where adiposity is consistently negatively associated with food avoidance scales of the CEBQ

(Mallan et al., 2013, Webber et al., 2009), albeit to a lesser extent, but this could be due to appetitive traits exerting a differential effect on body weight across the life course. In addition, when measured using an eating behaviour questionnaire, satiety responsiveness has been shown to be significantly negatively associated with body weight and energy requirements (Zuraikat et al., 2018). In this same study, there was also a trend towards a significant association with BMI. One study interested in the effect of mental work on satiety efficiency, reported that participants with the highest waist circumference had lower satiating efficiency in response to mental work (Salama et al., 2016). This suggests recognition of satiety signals may be related to fat distribution rather than body weight.

2.3.6 The Low Satiety Phenotype

A number of studies have taken the concept of satiety responsiveness further and used the satiety quotient to categorise individuals according to their individual satiating efficiency (Drapeau et al., 2013; Dalton et al., 2015; Arguin et al., 2017; Buckland et al., 2019; Drapeau et al., 2019). Once again the method used to categorise participants varied across the studies. Some studies used the mean SQ to classify participants according to their individual satiating efficiency (high vs. low) (Drapeau et al., 2013; Arguin et al., 2017; Drapeau et al., 2019) whilst others used a tertile split (Buckland et al., 2019). Dalton and colleagues (2015) used both the mean SQ and a measure of consistency to categorise individuals as low or high in satiety responsiveness. A median split for each condition was used. The low satiety phenotype was identified as those who had a low satiety quotient on at least three out of four occasions, whereas the high satiety phenotype were identified as those who had a high satiety quotient on at least three out of four occasions. To date research examining the low satiety phenotype has demonstrated that the phenotype is associated with a specific behavioural, psychological, physiological and metabolic profiles. One study has sought to characterise the metabolic profile of the low satiety phenotype in response to a test meal (Drapeau et al., 2013). In this study, blood samples were taken before and at regular intervals following a standardised test meal, from the low and the high satiety phenotypes determined using the satiety quotient, in a group of obese males. Although the low satiety phenotype group did not reveal any specific fasting metabolic profile, they displayed a blunted cortisol response to the test meal compared to the high satiety phenotype. Poor meal induced cortisol has been acknowledged as an indicator of dysregulation of the hypothalamic-pituitary-adrenal axis (Pruessner et al., 2003; Bjorntorp & Rosmond, 2000). Furthermore, women with high waist circumference also demonstrate a blunted cortisol response to a meal (Garcia-

Prieto et al., 2007). These results are consistent with those of other studies that have reported a positive association between awakening cortisol response and SQ for fullness (Therrien et al., 2008). Whilst the study conducted by Drapeau and colleagues (2013) did not reveal a specific metabolic profile for the low satiety phenotype, the physiological variables assessed were somewhat limited and the lack of associations with SQ may not mean that metabolic/physiological components are not associated with the low satiety phenotype. For instance, gut peptide such as ghrelin, GLP-1 and PYY could in fact be implicated.

Another study has reported that the low satiety phenotype was characterised by distinct behavioural and psychological factors, with a particular focus on hedonic risk factors (Dalton et al., 2015). In this study SQ was assessed over four weeks and in response to different energy loads. It was reported that the low satiety phenotype had higher RMR, greater levels of Disinhibition and reported feeling a lower control over food cravings. In addition, they consumed more energy and exhibited greater wanting for high fats foods. The inverse pattern of characteristics was observed in the high satiety phenotype. This study provides additional support for the LSP by extending the associated risk profile.

In addition to assessing satiety responsiveness, categorising individuals according to their satiating efficiencies and then characterising the satiety phenotypes; a number of studies have also included an intervention. These are therefore able to report the outcome of the intervention for the high vs. the low satiety phenotype. Firstly, the impact of a non-restrictive satiating diet was assessed in obese males displaying a high or a low satiety phenotype (Arguin et al., 2017). In this study the low satiety phenotype lost less weight than the high satiety phenotype. This finding is consistent with that of another intervention study conducted in females which reported that the low satiety phenotype lost less weight and had smaller reductions in waist circumference compared to the high satiety phenotype (Buckland et al., 2019). Taken together these findings suggest that in addition to an increased susceptibility to overconsumption and therefore a risk of weight gain the low satiety phenotype also display greater resistance to weight loss. In their study Buckland and colleagues compared two different weight loss programmes and participants underwent high and low energy dense laboratory test days. They established that the low satiety phenotype showed greater preference for high energy dense food, and under high energy dense conditions consumed more snacks compared with the high satiety phenotype. There were however no differences under low energy dense

conditions. This has resulted in the suggestion that low energy dense meals can improve regulation of energy intake in the low satiety phenotype and may be beneficial for long term weight loss. In the study, conducted by Buckland and colleagues, the LSP reported less control over eating, which is consistent with previous research (Dalton et al., 2015), as well as more difficulty with programme adherence, which is an interesting finding that warrants further investigation. Whilst these studies are in agreement that the low satiety phenotype display greater resistance to weight loss, there is evidence to suggest this may not always be the case. In a study which assessed energy restriction in the low satiety phenotype (Drapeau et al., 2019) similar weight loss was observed between low and high satiety responders. However, changes in eating behaviour traits, as a result of the energy restriction, differed depending on the level of satiety responsiveness. An energy restricted weight loss intervention seemed to trigger changes in the low satiety phenotype thereby increasing susceptibility to further weight gain. In this study researchers found a higher increase in restraint and lower decrease in disinhibition in the low satiety responders compared to the high satiety responders as a result of energy restriction.

2.4 Reliability of the Satiety Quotient

Despite high interindividual variability in SQ, intraindividual variability in SQ is low. In their study, Drapeau and colleagues demonstrated good reproducibility of the SQ (r = 0.5-0.7) when measures were repeated over 2-4 weeks (Drapeau et al., 2013). In addition, SQ for Hunger has shown good reliability over 4 weeks, and in response to different energy loads (Dalton et al., 2015). Taken together the findings suggest that the SQ shows promise as a stable individual marker for satiety that can be used to characterise the low satiety phenotype. However, while these studies provide support for the use of the SQ as a method of assessing satiety responsiveness and identifying the low satiety phenotype, more research is needed to address reliability of the measure over longer periods of time.

2.5 Clinical Implications

Based on the continued increase in population estimates of obesity, there is a clear need for more personalised intervention approaches. Behavioural phenotyping based on underlying mechanisms that effect appetite regulation and behaviour, such as satiety responsiveness, could help match individuals with targeted prevention and intervention approaches. Some research has explored this idea and demonstrated the importance and

provided support for this suggestion. For instance, individuals with low satiety responsiveness show greater resistance to weight loss (Buckland et al., 2019), providing a clear rationale for an individualised approach. Similarly, energy restricted weight loss can trigger undesirable changes in some eating behaviour traits in low satiety responders, which may contribute further to the susceptibility to weight gain (Drapeau et al 2019).

This review of the literature demonstrates that research on satiety responsiveness, specifically measured using either the Satiety Quotient or Adult Eating Behaviour Questionnaire is still in its infancy. Furthermore, there remains to be conducted a systematic investigation to assess the reliability and validity of the Satiety Quotient as a measure of satiety responsiveness. However, taken together the existing research presented here does suggest that increasing recognition is now being given to individual variability in the expression of appetite, and that low satiety responsiveness warrants further investigation. The current thesis will therefore build on existing evidence and investigate the role of individual differences in satiety responsiveness on appetite control.

2.6   Thesis Aims and Objectives

- To determine the validity and reliability of the satiety quotient as a measure of satiety responsiveness and as a method to categorise individuals according to satiety efficiency.
- To examine the effect of macronutrient manipulation (high vs. low fat) on the satiety quotient and to determine the extent to which the SQ is a consistent across dietary conditions.
- To establish whether weak satiety responsiveness, determined using the SQ, identifies a distinct phenotype, termed the low satiety phenotype, which is characterised by behavioural, psychological, physiological, metabolic risk factors for overconsumption.
- To examine the impact of snack foods which vary nutritionally in their satiating potential, in the low satiety phenotype compared to the high satiety phenotype.
- To explore the relationship between gut hormones and satiety responsiveness.

Chapter 3 General Methodology

3.1 Ethical Considerations

Ethical approval was obtained for each study from the Board of Ethics at the School of Psychology, University of Leeds. Each study met the ethical requirements of the School of Psychology and followed the code of ethics and conduct of the British Psychological Society. Written informed consent was obtained for all participants prior to any study commencing. While all study procedures were explained to participants in advance of obtaining informed consent, the specific objectives of the studies were not revealed until participants were debriefed in order to reduce demand characteristics. Participants were informed of their right to withdraw from the study without having to provide a reason. On completion of a study participants were debriefed and given the opportunity to ask questions. In all studies participants received a monetary payment for their participation.

3.2 Participant Recruitment

All participants were recruited via a University of Leeds email distribution list, which staff and students, as well as members of the public are able to sign up to. Each recruitment email included some information about the study, the inclusion and exclusion criteria and an online screening questionnaire which was used to determine eligibility. The inclusion and exclusion criteria for each study are described in greater detail in the method section of each experimental chapter. Eligible participants were invited to a screening session at the Human Appetite Research Unit, to confirm eligibility and have the study procedure presented to them before providing their written informed consent.

3.3 Anthropometrics and Body Composition

It is well established that self-report measures of height and weight are often inaccurate. Individuals tend to over-estimate their height while under estimating their weight (Palta, Prineas, Berman & Hannan, 1982; Taylor et al., 2006) and this is especially true for certain subgroups. For example, research suggests that overweight and obese individuals under-report their weight to a greater extent than normal weight individuals, and older

adults tend to over-report their height more than younger adults (Dekkers, van Wier Hendriksen, Twisk & Van Mechelen, 2008; Larsen, Ouwens, Engels, Eisinga & van Strien, 2008; Rowland, 1990). For this reason, in all studies participants height and weight were measured to check their eligibility during the screening session. Height and weight was measured using a wall mounted stadiometer and an electronic balance, to the nearest 0.1cm and 0.1kg, respectively, under controlled conditions (without shoes, wearing light clothing and following an overnight fast). Following this check, eligible participants had their body composition measured using air-displacement plethysmography (BodPod, Concord, USA). This method has been validated in both normal weight (Fields, Goran & McCrory, 2002) and obese adults (Goran et al., 2002). More specifically, a review of the literature by Fields and colleagues (2002) suggests that the estimation of body fat from air-displacement plethysmography is within 1 to 2% of that of DEXA and hydrostatic weighing methods. The BodPod uses air-displacement plethysmography to provide an estimate of fat mass, fat free mass and body fat percentage. Participants are required to sit in a sealed chamber (the BodPod), Body volume is assessed indirectly by measuring the volume of air a person displaces inside the enclosed chamber. Body volume is then combined with measured body mass in order to calculate body density. Equations are then used to provide an estimate of fat and fat free mass. This measure was conducted whilst participants were wearing a swim suit and cap, following an overnight fast and according to standard operating procedures. Air-displacement plethysmography was used to measure body composition during the Screening and Measures session in all studies. In addition, body composition was used to characterise the Low Satiety Phenotype in Chapters 4, 6, 7 & 8 of the current thesis.

3.4   Resting Metabolic Rate

Resting metabolic rate (RMR) was measured using an indirect calorimeter fitted with a ventilated hood (GEM; Nutren Technology Ltd, UK). The measurement of resting metabolic rate required participants to remain awake but motionless in a supine position for around 45 minutes, during which expired air was collected using a ventilated hood system. Firstly, the GEM was calibrated. Then values of VO_2 and VCO_2 were sampled every 30 seconds. Resting metabolic rate was calculated using standardised equations, from respiratory data averaged over the final 30 minutes, and expressed as kcal/day. This measure was conducted following an overnight fast and according to standard operating procedures. Resting metabolic rate was measured during the Screening and Measures

session in all studies. Resting metabolic rate was then used to individually calibrate fixed energy meals to provide participants with a % of their resting energy requirements in Chapters 4, 6, 7 & 8. In addition, resting metabolic rate was used to characterise the Low Satiety Phenotype in Chapters 4, 6, 7 & 8 of the current thesis.

3.5   Eating Behaviour Questionnaires

The studies in the current thesis used a number of validated psychometric questionnaires to examine individual differences in eating behaviour. These included the Three Factor Eating Questionnaire (TFEQ), Control of Eating Questionnaire (CoEQ) and Binge Eating Scale (BES). Each eating behaviour questionnaire is described in detail below.

3.5.1   Three Factor Eating Questionnaire

The Three Factor Eating Questionnaire was developed by Stunkard and Messick (TFEQ; Stunkard & Messick, 1985) and measures three aspects of eating behaviour including Restraint, Disinhibition and Hunger. The Three Factor Eating Questionnaire has been shown to have good internal validity (Stunkard & Messick, 1985). The questionnaire comprises 51 items. Participants are required to respond either true or false to the first 36 items. The other 15 items required participants to select a response from a choice of four, varying in level of agreement with a statement. Responses are scored and then summed, with higher scores denoting higher levels of eating disturbances. The Three Factor Eating Questionnaire was completed during the Screening and Measure session in all studies. The subscales of the Three Factor Eating Questionnaire were used to characterise the Low Satiety Phenotype in Chapters 4, 6, 7 & 8 of the current thesis.

3.5.2   Control of Eating Questionnaire

The Control of Eating Questionnaire was originally developed by Hill and Blundell (CoEQ; Hill, Weaver & Blundell, 1991) and has subsequently been modified and shown to have good internal consistency by Dalton and colleagues (Dalton, Finlayson, Hill & Blundell et al 2015). It measures general appetite and mood as well as frequency and intensity of food cravings and level of control over these food cravings. The CoEQ has four subscales: Craving Control, Craving for Savoury, Craving for Sweet and Positive Mood. The questionnaire comprises 21 items. Participants are required to respond to the items using 100-mm visual analogue scales (VAS), with the exception of item 21 which allows participants to enter their own response, with items relating to each subscale averaged to create a final score. Participants were required to answer according to their

experiences over the previous seven days or according to their experiences over the previous 24-hours. The Control of Eating Questionnaire was completed during the Screening and Measures session in all studies. The subscales of the Control of Eating Questionnaire were used to characterise the Low Satiety Phenotype in Chapters 4, 6, 7 & 8 of the current thesis. In addition, the 24hour CoEQ was used in Chapter 7 as part of a Questionnaire given to participants following each experimental session.

3.5.3   Binge Eating Scale

The Binge Eating Scale was developed by Gormally et al (BES; Gormally et al., 1982) and measures the severity of Binge Eating. The Binge Eating Scale has been shown to have good internal validity, with a Cronbach's alpha of 0.89 (Fritas, Lopes, Appolinario & Coutinho, 2006) and good test-retest reliability (Timmerman, 1999). The scale comprises 16 items; 8 items describe the feeling and emotions associated with binge eating and 8 items describe the behavioural manifestations of binge eating behaviour. Each item consists of three to four descriptive statements that increase in severity and participants are required to select the statement which is most descriptive of them. Scores are then summed to produce a total score ranging from 0 - 46, with higher scores denoting higher levels of binge eating. The Binge Eating Scale was completed by participants during the Screening and Measures session. In addition, Binge Eating Score was used to characterise the Low Satiety Phenotype in Chapters 4, 6, 7 & 8 of the current thesis.

3.6   Psychological Wellbeing Questionnaires

A range of different questionnaires were used in Chapter 8 of the current thesis, to assess psychological wellbeing including the Beck Depression Inventory (BDI-II; Beck, Steer & Brown, 1996), Perceived Stress Scale (PSS; Cohen, 1994), State Trait Anxiety Inventory (STAI; Spielberger, 1989). The Beck Depression Inventory (Beck et al., 1996) assesses symptoms of major depression. The scale comprises 21 items; all of which are multiple choice questions requiring one response. Scores are summed to produce a total score, with a maximum score of 63 and scores of 0-13, 14-19, 20-28, 29-63 indicating minimal, mild, moderate and severe depression, respectively. The Perceived Stress Scale (Cohen, 1994) assesses participants perception of stress and the extent to which they feel that life has been unpredictable, uncontrollable or overloaded over the previous 2 weeks. The scale comprises 10 items and requires participants to respond on a 5-point Likert scale. Scores on the PSS greater than 20 are indicative of a high stress level. Furthermore,

the State Trait Anxiety Inventory (Spielberger, 1989) consists of two parts: part one assesses state anxiety (anxiety right now, at this moment) and part two assesses trait anxiety (anxiety generally). Each part of the STAI comprises 20 questions and requires participants to respond on a 4-point Likert scale. Higher scores for both measures indicate greater levels of anxiety.

3.7   Subjective Appetite Sensations

Subjective appetite sensations can be assessed using visual analogue scales (VAS). VAS comprise a 100mm horizontal line, anchored at each end by subjective statements (Hill and Blundell 1982). Participants are required to mark along the line to indicate the intensity of a subjective sensation at that point in time, allowing the sensation to be measured and quantified. The use of VAS to measure appetite is commonly used within research and is accepted as one of the best methods available. VAS ratings are sensitive to experimental manipulations (Stubbs et al., 2000) and have shown test-retest reliability (Blundell et al., 2010). VAS can be administered using pen and paper or on a hand-held Electronic Appetite Rating System (EARS-II, (HP iPAQ)). The traditional pen and paper VAS method is quick and simple and low burden for participants. However, this method of administering VAS requires each line to be measured and for the data to be manually inputted which is time consuming and introduces the possibility of human error. Furthermore, whilst the pen and paper method is useful under tightly controlled laboratory conditions, it has limitations when used in free living situations or instances where participants are able to leave the research unit. For example, when unsupervised the pen and paper method is much less reliable. Overall, compliance tends to be low as questions may be omitted, incorrectly marked or completed at the incorrect time points. To overcome these limitations an Electronic Appetite Rating System (EARS-II, (HP iPAQ)) can be used. The EARS-II incorporates VAS on a portable handheld computer, and has previously been validated (Gibbons, Caudwell, Finlayson, King, & Blundell, 2011). The EARS-II has a number of advantages over the traditional pen and paper method. For instance it includes the ability to set an alarm that prompts the completion of ratings, as well as collecting a time and date stamp for each entry allowing the research to check compliance with the study procedures. In the current thesis, subjective appetite sensations were assessed in Chapters 4, 5, 6, 7 & 8 using 100-mm VAS presented on an Electronic Appetite Related System (EARS-II, HP iPAQ System). Measures of hunger ('*How hungry do you feel right now*?') and fullness ('*How full do you feel right now*?')

were anchored at each end with the statements '*Extremely*' and '*Not at all*'. Ratings of prospective consumption ('*How much food could you eat right now*?') and desire to eat ('*How strong is your desire to eat*?') were anchored at each end with the statements '*None at all*' and '*A very large amount*' and '*Not very strong*' and '*Very strong*', respectively. Participants completed ratings at baseline, before and after each event in the procedure and at regular intervals throughout the day. The portable handheld computer was set to alert participants as to when to complete the VAS ratings, ensuring collection at precise time points throughout the day both within the research unit and in a free living environment in between the study test meals. Subjective ratings of hunger were using in the calculation of the Satiety Quotient. In addition, appetite sensations were used to characterise the Low Satiety Phenotype in Chapters 4, 6, 7 & 8.

3.8   Energy Intake

Measures of free living energy intake for example food diaries or dietary records are high in ecological validity, however data collected from these methods can be unreliable. For instance they rely on the participants ability to remember what they have consumed and also their willingness to truthfully report all items consumed. Furthermore, evidence suggests that recording food intake may result in the individual consuming less than they usually would due to an increase in self-monitoring (Baker & Kirschenbaum, 1993; Goris, Westerterp-Plantenga & Westerterp, 2000). Dietary recall procedures, such as the Automated Multiple Pass Method (AMPM; Moshfegh et al., 2008) can be used as an alternative to help reduce the impact of issues such as this. On the other hand, assessing energy intake in a laboratory setting has many advantages. High levels of control, precision and accuracy can be achieved over experimental variables such as energy and nutrient intake. There are two types of energy intake assessment that can be carried out in a laboratory. Firstly, fixed energy intake, where the amount of food to be consumed is determined by the researcher. Secondly, ad libitum energy intake, where participants determine their own energy intake. However, assessing energy intake in a laboratory setting can inhibit the participants natural behaviour due to the artificial environment. Consequently, there is a trade-off between exactness and naturalness (Blundell et al., 2009). In the current thesis energy intake was assessed primarily through the assessment of laboratory energy intake within the Human Appetite Research Unit (HARU) at The University of Leeds. The Human Appetite Research Unit is a specially designed research facility that allows for the assessment of food intake in a controlled environment. The

research unit includes individual experimental cubicles, in which participants are shielded from confounding and extraneous variables that may have impacted their energy intake behaviour, for example, smells, sounds, competing activities and social stimuli.

3.8.1 Fixed Energy Test Meals

Fixed intake test meals can be fixed either by the volume or the energy content of the food provided. Fixed energy test meals allow for the consumption of food to be manipulated and standardised across participants. Fixed energy test meals were used in Chapters 4, 5, 6, 7 & 8 of the current thesis. All fixed energy test meals were individually calibrated to provide participants with a fixed amount of their daily energy requirements (measured RMR) to allow for individual differences in energy needs. Each experimental chapter provides further details of the fixed energy test meals that were used. For all, participants were given a fixed amount of time to consume the meal in its entirety. In Chapters 5, 6 & 7 of the current thesis fixed energy test meals were used as part of a preload design, where across conditions the meal varied in energy and/or macronutrient.

3.8.2 Ad Libitum Test Meals

Energy intake can also be assessed using ad libitum test meals, whereby the researcher provides the participant with food in an unlimited amount. A range of foods are usually provided which allows for the assessment of the amount of food eaten (quantitative) as well as the type of food eaten (qualitative) e.g. based on nutrients and/or sensory aspects. The assessment of energy intake through ad libitum test meals can be more naturalistic than for example fixed energy test meals, as the participant is able to control their food intake similarly to how they would in everyday life. However, attention must be applied when designing ad libitum test meals as research has shown that factors such as variety, palatability and energy density can prompt over or under eating (Blundell & Macdiarmid, 2006; Hetherington, Foster, Newman, Anderson & Norton, 2006; Raynor & Epstein, 2001; Rolls, Van Duijenvoorde & Rolls, 1984). In addition, caution must be exercised with regards to the portion size of the ad libitum test meal. Previous research has demonstrated that, regardless of participant characteristics (e.g. gender, BMI, level of restraint) or method of service, larger portion sizes lead to increased energy intake (Rolls, Morris & Roe, 2002). Ad libitum test meals were used in Chapter 4, 5, 6, 7 & 8 of the current thesis. Each experimental chapter provides further details of the ad libitum test meals that were used. For all, participants were given a fixed amount of time and instructed to consume as much or as little as they wanted but to eat until they reached a

comfortable level of fullness. Food was weighed pre and post consumption to the nearest 0.1g to determine energy intake. In Chapter 7 & 8 free-living ad libitum snack food intake was assessed using a snack box which participants took away with them. Participants were informed that they could consume as much or as little as they wanted, but that they should not share, give away or dispose of any of the food items. Any uneaten food items, including the packaging, were returned to the research unit the following day.

3.9   The Leeds Food Preference Questionnaire

The Leeds Food Preference Questionnaire (LFPQ; Finlayson, King & Blundell, 2008) was used in the current thesis to assess explicit liking, explicit wanting and implicit wanting. The LFPQ has been previously validated in a wide range of research (Finlayson et al., 2011; Griffioen-Roose et al., 2010; Verschoor, Finlayson, Blundell, Markus & King, 2010). The validated list of foods, which vary in nutritional and sensory qualities, used in the LFPQ is shown in Table 1. Where participants report a low acceptance of any of these foods, determined prior to the measure being conducted, there are additional images for each category which can be used as substitutions. To measure explicit liking food images are presented individually, in a randomised order and participants are required to rate '*How pleasant would it be to taste some of this food now?*' on 100mm VAS. Similarly, to measure explicit wanting participants were required to rate '*How much do you want some of this food now?*'. To measure implicit wanting images of food were presented to participants in pairs and participants were required to respond as quickly and as accurately as possible to 'Which food do you most want to eat now?'. Reaction time for each response is covertly recorded. The LFPQ produces scores for the different food groups resulting in four categories: high fat savoury, low fat savoury, high fat sweet and low fat sweet. For explicit liking and explicit wanting scores are obtained by averaging the ratings for each category, with higher scores indicating higher explicit liking or explicating wanting for that category. For implicit wanting reaction times are transformed to a standardised score using a validated algorithm (Greenwald, Nosek & Banaji, 2003), with higher scores indicating greater implicit wanting. In addition, for both explicit liking and implicit wanting, the mean for low fat scores were subtracted from the mean of high fat scores to produce an appeal bias for high fat versus low fat. In the current thesis liking and wanting was assessed using the LFPQ in Chapters 4, 6 & 7. The LFPQ was administered prior to lunch when fasted (for 4hrs) and according to standard operating procedures (Oustric et al., 2020). These measures of liking and

wanting were used to characterise the low satiety phenotype in Chapters 4, 6, 7 & 8. In addition, in Chapter 7, the LFPQ was used to examine individual differences in liking and wanting following the consumption of different snack foods.

Table 3.1. Food images used in the Leeds Food Preference Questionnaire.

Savoury		Sweet	
High Fat	Low Fat	High Fat	Low Fat
Garlic Bread	Cucumber	Jam Biscuits	Apple
Crisps	Bread Roll	Doughnuts	Strawberries
Chips	Pilau Rice	Chocolate Fingers	Skittles
Peanuts	Potatoes	Chocolate	Marshmallows

3.10   Appetite Related Peptides

Blood samples were collected and prepared to allow for the assessment of appetite related peptides in Chapter 8 of the current thesis. In this study, participants were fitted with a venous cannula upon arrival at the research unit and blood samples were taken at intervals before (-10, 0 mins) and for three hours following a standardised test meal (+10, +20, +30, +45, +90, +120, +180 mins). The cannula was flushed with 2.5ml saline solution before and after each blood sample was taken. Blood samples were collected into 10ml syringes and then transferred to EDTA-containing Monovette tubes. The tubes contained a mixture of inhibitors to prevent degradation of the peptides to be assessed. After collection, samples were centrifuged for 10 minutes at 4°C and 4000 rpm. Samples were immediately pipetted into Eppendof tubes and stored at -80°C awaiting analysis. Analysis of appetite related peptides was conducted off site by an expert in this area.

3.11   The Satiety Quotient

The satiety quotient (SQ) is a measure of the satiating effect of a food on an individual. The satiety quotient can be calculated for hunger, fullness, desire to eat and prospective consumption; as well as for the mean of these appetite sensations. The SQ has been validated in previous research (Green et al., 1997; Drapeau et al., 2007; Drapeau et al., 2013). A higher SQ represents a stronger appetite response to, whereas a lower SQ represents a weaker response. The following formula was used to calculate SQ:

$$\text{SQ (mm/kcal)} = \frac{[\text{rating before eating episode} - \text{mean post meal rating}]}{\text{energy content of the test meal (kcal)}} \times 100$$

In the current thesis, the satiety quotient was used in Chapters 4, 6, 7 & 8 to group participants according to their satiating efficiency. Participants were categorised as either low or high in satiety responsiveness and termed the low and high satiety phenotype. In addition, in Chapter 5 of the current thesis, the satiety quotient enabled the assessment of the satiating efficiency of foods which differ in their macronutrient composition.

3.12   Statistical Analyses

Data were analysed using Statistical Package for the Social Sciences Version 22 (SPSS: IBM Corporation, Somers, New York). All statistical procedures are described in greater detail in the method section of each experimental chapter. For all analyses an α-level of .05 was used to determine statistical significance. Where appropriate Greenhouse-Geisser probability levels were used to adjust for non-sphericity. Where significant effects were obtained post hoc analyses, with a Bonferroni correction for multiple comparisons were conducted. Cohen's d was used as a measure of effect size (Note: effect size was calculated and reported in Study 1, 3, 4 & 5). Data from the online screening questionnaire were exported to Microsoft Excel. All eating behaviour and psychological wellbeing questionnaires were scored using Microsoft Excel, in accordance with the original authors instructions. Data collected using E-Prime (Leeds Food Preference Questionnaire) were exported to Microsoft Excel using E-DataAid. Microsoft Excel was used to collate and calculate the variables for export to SPSS. Where data is presented graphically these have been produced by transferring the relevant descriptive statistics from SPSS to Microsoft Excel and using the chart function.

Chapter 4

Assessment of the Reliability and Validity of the Satiety Quotient as a Measure of Satiety Responsiveness

4.1   Abstract

Background: Some individuals report a weak satiety response to food and as a result may be susceptible to overeating and obesity. The satiety quotient (SQ) is one measure that has been proposed to assess satiety responsiveness. The present studies (Study 1a and 1b) explored the reliability and validity of the satiety quotient as a measure of satiety responsiveness and as a method to classify individuals as low or high satiety phenotypes.

Method: Using a repeated measures design, sixty-one participants (age: 27.7±11.1 years, BMI: 24.9±3.1 kg/m²) recorded subjective appetite sensations during the postprandial period following a fixed energy breakfast on two separate occasions across two studies (Study 1a and 1b). Body composition was measured using air plethysmography and resting metabolic rate was measured via indirect calorimetry. Ad libitum energy intake was assessed at lunch and/or dinner. In addition, the Three Factor Eating Questionnaire, Binge Eating Scale and Control of Eating Questionnaire were used to assess eating behaviour and craving for food. Food reward was measured using the Leeds Food Preference Questionnaire. Satiety responsiveness was assessed using the satiety quotient. A tertile spilt of SQ for Hunger was used to determine low and high satiety phenotypes. The reliability and validity of the satiety quotient was determined by assessing the consistency of the SQ across measures and then by exploring associations between appetite control and the SQ. All measures, except energy intake at lunch, were common to both Study 1a and Study 1b. Study 1a and 1b was analysed and reported separately.

Results: The satiety quotient for all appetite sensations showed good reliability between measures. Satiety quotient was associated with risk factors for overconsumption including TFEQ Hunger, energy intake and resting metabolic rate. The low satiety phenotype was characterised by an impaired capacity to detect appetite sensations and

reduced intensity and duration of post ingestive activity. Furthermore, they displayed greater TFEQ Hunger, greater wanting for sweet foods and lower control over cravings.

Conclusion: The satiety quotient is a reliable measure of satiety responsiveness, that can be used to identify individuals who reliably experience a weak or strong satiating efficiency. The low satiety phenotype are characterised by distinct behavioural and psychological characteristics that may increase their susceptibility to overeating.

4.2   Introduction

The measurement of subjective appetite sensations, using visual analogue scales, before and after a standardised test meal, enables the calculation of the satiety quotient (SQ), a marker of satiating efficiency. Originally developed by Green and colleagues in 1997, the SQ represents the extent to which a preload can alter subjective appetite sensations and is expressed per unit of energy intake (Green et al.1997). The SQ can be used to classify individuals according to their satiety signalling capacity in response to a standardised meal. A higher SQ represents a stronger appetite response or greater satiety signalling capacity to food consumed whereas a lower SQ represents a weaker response. The satiety quotient can be calculated for hunger, fullness, desire to eat or prospective consumption; as well as for the mean of the four appetite sensations. Some studies have calculated SQ for all four appetite sensations (Drapeau et al., 2005, Drapeau et al., 2007, Drapeau et al., 2013). Whilst other studies have used just one appetite rating. Both Green (1997) and Dalton (2015) and colleagues used hunger to calculate SQ. Whereas in their study Buckland and colleagues calculated SQ using fullness appetite ratings (Buckland et al., 2019). What is more, some studies have used a mean of the four subjective appetite ratings to calculate a mean SQ score (Drapeau et al., 2013, Drapeau et al 2019).

There is support for the use of visual analogue scales and the satiety quotient as methods of identifying the low satiety phenotype. Under standardised conditions, i.e. after a 12 hour fast, alone and in a quiet room free from distractions, appetite sensation measurements using visual analogue scales have been shown to be highly reliable both before and in response to a meal (Arvaniti et al., 2000). In addition, it has been shown that the use of visual analogue scales to characterise appetite sensations has good within-subject reliability and validity (Stubbs et al., 2000). Stubbs and colleagues (2000) demonstrated that these sensations predict both meal initiation and the amount of food eaten, and that they are sensitive to experimental manipulations. Furthermore, the SQ has

been validated in previous research (Drapeau et al., 2007; Green et al., 1997). Using the satiety quotient and a test meal Drapeau and colleagues have demonstrated SQ for fullness to be negatively associated with both total energy intake and relative energy intake (total energy intake - metabolic rate) in normal weight, obese and reduced-obese individuals (Drapeau et al., 2005). Therefore, were able to conclude that individuals with low SQ, who experienced almost no change in meal induced fullness, had higher energy intakes. These findings were confirmed in a subsequent study (Drapeau et al., 2007) conducted on a larger more homogenous sample of obese men and women. Here the negative relationship between SQ for fullness and total energy intake proved stronger for women. Together these findings indicate that individuals characterised as having a low SQ, therefore represent the low satiety phenotype, have weaker appetite sensation responses following a meal and as a result could be more vulnerable to overconsumption. Additionally, despite high interindividual variability in SQ, intraindividual variability in SQ is low. In a more recent study Drapeau and colleagues have demonstrated good reproducibility of the SQ when measurements were repeated 2-4 weeks apart (Drapeau et al., 2012). Taken together the findings presented here suggest that the satiety quotient represents a stable individual marker for satiety efficiency and excess energy intake that can be used to measure satiety responsiveness and identify the low satiety phenotype.

While research has demonstrated that the low satiety phenotype exhibits a weak satiety response following a caloric preload and greater total energy intake, which may increase susceptibility to weight gain and obesity; there have been few studies conducted specifically to characterise the low satiety phenotype (Drapeau et al., 2005, 2011, 2013; Barkeling et al., 2007). Nonetheless, the low satiety phenotype has been shown to be associated with a specific behavioural profile; comprising higher disinhibition, susceptibility to external hunger, anxiety and night eating symptoms. As well as lower awakening morning cortisol response and a blunted cortisol response to a test meal (Drapeau et al., 2013). However, studies that have used the satiety quotient as a measure of satiety responsiveness and subsequently proceeded to characterise the low satiety phenotype have typically only used a small sample of individuals, therefore interpretation and generalisation of these findings is limited. Thus, determining the reliability and the validity of the satiety quotient as a measure of satiety responsiveness as well as the characterisation of the low satiety phenotype requires some further attention.

4.2.1 Study Aims

The first aim of the current study was to determine the reliability and the validity of the satiety quotient as a measure of satiety responsiveness. This will involve comparing the SQ for the two measures as well as the different appetite sensations. In addition, by exploring what makes individuals who are identified, using the satiety quotient, as low or high satiety responders different; considering a range of behavioural, psychological, physiological and metabolic factors. The study also aimed to examine subjective appetite sensations for hunger, fullness, desire to eat and prospective consumption for individuals identified as low or high satiety responders. It was hypothesised that it would be possible to reliably identify individuals who experience a weak or strong appetite response using the SQ. In addition, the SQ is likely to be associated with factors linked to increased risk of overconsumption. Finally, individuals identified as low satiety responders will be expected to report greater levels of hunger, desire to eat and prospective consumption and lower levels of fullness across the day when compared to high satiety responders.

4.3 Method

4.3.1 Participants

Sixty-one participants (age: 27.7±11.1 years, BMI: 24.9±3.1 kg/m²) were recruited via a University of Leeds email distribution list, which staff and students as well as members of the public are able to sign up to. Eligibility was determined using an online screening questionnaire. The inclusion criteria for the study was healthy male or female participants, aged 18-55 years, with a BMI between 23.0-32.0 kg/m². Participants who were taking medication known to affect appetite, currently dieting to lose or maintain weight, not regular breakfast consumers, smokers, reported a history of eating disorders or were unfamiliar with or disliked any of the study foods were excluded. Eligible participants were invited to a screening session to confirm their eligibility and have the study presented to them. All participants provided written informed consent and all research procedures were reviewed and approved by the University of Leeds, School of Psychology Ethics committee. Participants received £20 for their participation.

4.3.2 Design

The studies followed a repeated measures design. Each participant attended the Human Appetite Research Unit at the University of Leeds on three occasions: this included a

screening and measures session, followed by two experimental sessions. These visits were scheduled at least seven days apart and for all visits participants were required to fast from 10pm the evening before to ensure a standardise fasting state. Participants were also instructed not to consume alcohol or engage in physical activity for 24-hours and not to consume caffeine for 12-hours prior to the sessions. Compliance with these instructions was assessed at the beginning of each session by self-report. During the experimental sessions participants consumed their breakfast, lunch and dinner in the research unit. Participants were free to leave the research unit in between the meals but were instructed not to eat or drink anything besides water. Ratings of subjective appetite were taken every 60 minutes throughout the test day using a validated hand-held Electronic Appetite Rating System (EARS-II; Gibbons, Caudwell, Finlayson, King & Blundell, 2011). The breakfast provided was fixed and individually calibrated to provide participants with 25% of their individual energy requirement. Together these measures enabled the satiety quotient to be calculated, and for high and low satiety phenotypes to be identified. Ad libitum test meals were used to assess energy intake. Food reward was measured using the Leeds Food Preference Questionnaire and craving for food was assessed using the Control of Eating Questionnaire. The design of the studies was the same for Study 1a and Study 1b, except for the test meal provided to participants at lunch.

4.3.3   Measures

All measures were conducted within the Human Appetite Research Unit (HARU) at the University of Leeds; except the screening questionnaire which was completed online. All measures, except energy intake at lunch, were common to Study 1a and Study 1b.

4.3.3.1   Online Screening Questionnaire

An online screening questionnaire was used to identify eligible participants based on the inclusion and exclusion criteria. Participants who met the criteria were sent a copy of the participant information sheet and invited to a screening and measures session.

4.3.3.2   Resting Metabolic Rate

Participants resting metabolic rate was assessed during the measures session, using an indirect calorimeter fitted with a ventilated hood (GEM; Nutren Technology Ltd); described in more detail in Chapter 3. Resting metabolic rate was used to standardise the fixed energy test meals served to participants as part of the experimental sessions, so that each meal represented the same % of that person's basic energy requirement.

4.3.3.3   Anthropometrics and Body Composition

Standing height without shoes was measured to the nearest 0.5cm using a stadiometer and body weight was measured to the nearest 0.1kg using an electronic balance. Waist circumference (cm) was measured at the participants naval after expiration. In order to obtain an estimate of participant's fat mass, fat free mass and percentage body fat air plethysmography (BodPod, Concord, CA, USA) was used. Anthropometric and body composition measures were conducted during the measures session according to standard operating procedures and are described in more detail in Chapter 3.

4.3.3.4   Eating Behaviour Questionnaires

The Three Factor Eating Questionnaire (TFEQ; Stunkard & Messick, 1985), Control of Eating Questionnaire (CoEQ; Hill et al., 1991) and Binge Eating Scale (BES; Gormally et al., 1982) were completed during the measures session, to assess levels of restraint, disinhibition and hunger; mood, appetite and experience of food craving, as well as binge eating severity. These measures are described in more detail in Chapter 3.

4.3.3.5   Subjective Appetite Sensations

Ratings of hunger, fullness, desire to eat and prospective consumption) were assessed using 100-mm VAS presented on an Electronic Appetite Rating System (EARS). These measures are described in more detail in Chapter 3. Ratings were completed at baseline, before and after each event in the procedure and at hourly intervals throughout the day.

4.3.3.6   Energy Intake

4.3.3.6.1   Fixed Energy Breakfast – Study 1a and Study 1b

The fixed energy breakfast consisted of muesli (muesli base, raisins, sultanas and almonds) combined with natural yoghurt, semi-skimmed milk and honey. The breakfast was individually calibrated to provide participants with 25% of their individual energy requirement. The macronutrient content of the breakfast was fixed at 15% protein, 62% carbohydrate and 22% fat. See Table 1 for details of the breakfast food items. The amount of water served was adjusted so that the total weight of the breakfast was kept constant. Participants were given 15 minutes to consume the breakfast in its entirety.

Table 4.1. Nutritional information for the fixed energy breakfast items.

Breakfast Item	KCAL/100g	CHO/100g	FAT/100g	PRO/100g
Neal's Yard Muesli Base	360.0	70.0	5.0	13.0

Neal's Yard Raisins	268.6	69.3	0.0	2.1
Neal's Yard Sultanas	274.7	69.4	0.4	2.7
Yeo Valley Natural Yoghurt	82.0	6.5	4.2	4.6
Sainsbury's Runny Honey	319.5	84.3	0.2	0.4
Semi-Skimmed Milk	50.0	4.8	1.1	3.6

4.3.3.6.2   Fixed Energy Lunch – Study 1a

The fixed energy lunch served to participants consisted of chilli con carne and rice and was individually calibrated to provide participants with 30% of their measured resting energy requirement, see Table 2 for details. Lunch was served 4 hours following breakfast and participants were given 15 minutes to consume the lunch in its entirety.

Table 4.2. Nutritional composition of the fixed energy lunch – Study 1a.

Lunch Item	KCAL/100g	CHO/100g	FAT/100g	PRO/100g
Chilli Con Carne with Rice	126.0	12.2	4.1	8.5

4.3.3.6.3   Ad Libitum Lunch – Study 1b

Energy intake was assessed at lunch using an ad libitum test meal which consisted of chilli con carne and rice and strawberry yoghurt, see Table 3 for details of serving size and nutritional information for the lunch food items. Lunch was served 4 hours following breakfast and participants were instructed to consume as much or as little as they wanted but to eat until they reached a comfortable level of fullness. Food was weighed pre- and post-consumption to the nearest 0.1g to determine energy intake.

Table 4.3. Serving size and nutritional information for ad libitum lunch – Study 1b.

Lunch Item	Serving (g)	KCAL/ 100g	CHO/ 100g	FAT/ 100g	PRO/ 100g
Chilli Con Carne with Rice	900	126	12.2	4.4	8.5
Yeo Valley Strawberry Yoghurt	425	106	13.2	3.8	4.7
Sainsbury's Double Cream	45	439	1.5	47.5	1.5

Note: The cream was mixed with the strawberry yoghurt.

4.3.3.6.4   Ad Libitum Dinner – Study 1a and Study 1b

Energy intake was assessed at dinner using an ad libitum test meal which consisted of tomato and herb risotto, garlic bread, salad and chocolate brownies, served alongside water. See Table 4 for details of serving size and nutritional information for the dinner

food items. Dinner was served 4 hours following lunch and participants were instructed to consume as much or as little as they wished, but to eat until comfortably full. Food was weighed pre- and post-consumption to the nearest 0.1g to determine energy intake.

Table 4.4. Serving size (g) and nutritional information for the ad libitum dinner items.

Dinner Item	Serving (g)	KCAL/ 100g	CHO/ 100g	FAT/ 100g	PRO/ 100g
Uncle Bens Tomato & Herb Risotto	900	178	31.4	3.9	3.7
Sainsbury's Olive Oil	45	823	0.5	91.5	0.5
Garlic Bread	260	443.8	58.8	18.5	8.9
Lettuce	50	14.0	1.8	0.3	0.7
Cucumber	115	10.0	1.5	0.1	0.7
Tomatoes	115	20.0	3.1	0.5	0.7
Chocolate Brownies	140	437.0	56.1	20.4	6.0

Note: The olive oil was mixed in with the risotto.

4.3.3.7   Leeds Food Preference Questionnaire

The Leeds Food Preference Questionnaire (LFPQ) was used to assess food reward. Participants completed the LFPQ prior to the lunch to assess explicit liking and implicit wanting for a selection of food images. The LFPQ in described in detail in Chapter 3.

4.3.3.8   Satiety Quotient

VAS ratings (Hunger, Fullness, Desire to Eat and Prospective Consumption) were used to calculate satiety quotient for the 105-minute period post breakfast (VAS ratings were taken +15 min, +60 min and +120 min post breakfast). Satiety quotient for Hunger was then used to characterise participants as high or low in satiety responsiveness. The satiety quotient is described in greater detail in Chapter 3.

The following formula was used to calculate SQ:

$$SQ \ (mm/kcal) = \left(\frac{\text{rating before eating} - \text{mean of the 105-min post meal ratings}}{\text{energy content of the test meal (kcal)}} \right) \times 100$$

4.3.4   Procedure

For all sessions participants arrived at the research unit between 8.00-9.30am following an overnight fast. Participants were instructed not to consume alcohol or engage in

physical activity for 24-hours and not to consume caffeine for 12-hours prior to the sessions. At the start of the screening and measures session participants eligibility was confirmed, they were then provided with a written and verbal explanation of the research requirements. They were given the opportunity to ask any questions before providing written informed consent. Height, weight, waist circumference, resting metabolic rate and body composition were measured. Participants also completed a number of eating behaviour questionnaires (TFEQ, CoEQ, BES). For the experimental sessions, participants were shown to a research cubicle on arrival, where they completed a set of baseline VAS appetite ratings and consumed breakfast. Following breakfast a second set of VAS ratings were completed and participants were free to leave the research unit but were asked to return four hours later for lunch. During this time the EARS-II prompted completion of VAS rating at sixty minute intervals. During the lunchtime session participants completed the LFPQ and were served either a fixed energy or ad libitum lunch. Participants completed VAS ratings before and after each event in the lunchtime procedure. Following lunch participants were once again free to leave the research unit but were asked to return four hours later for dinner. Participants continued to complete VAS ratings prompted by the EARS-II at 60 minute intervals while away from the research unit. Participants completed VAS ratings before and after the dinner test meal. Following the dinner test meal participants were free to leave, until the next experimental session. On completion of all study procedures participants received a written and verbal debrief and were compensated for taking part in the study. See Figure 1 and Figure 2 below for a schematic representation of the study procedure for Study 1a and Study 1b.
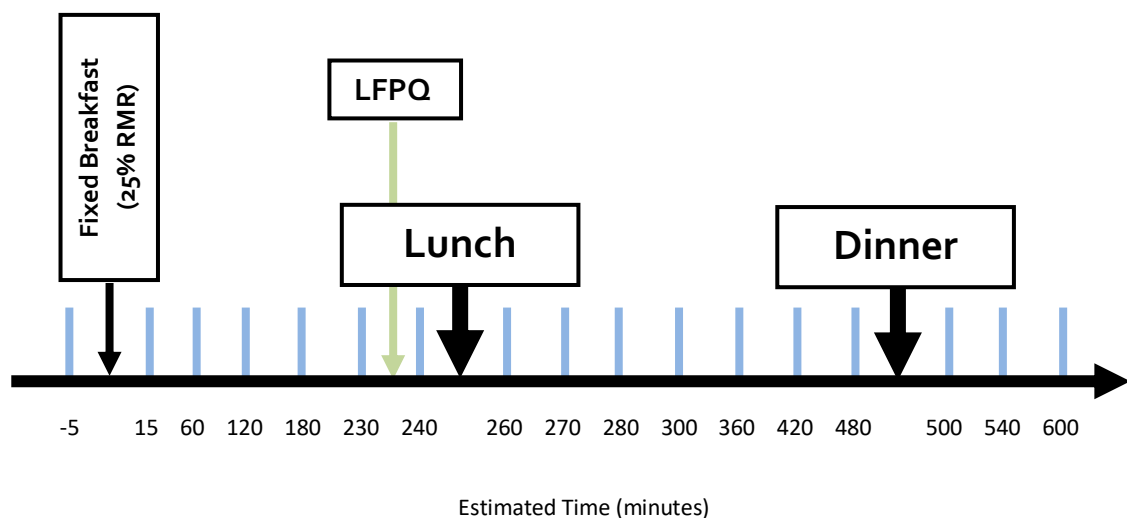
Figure 4.1. Schematic representation of the experimental session - Study 1a.

Fixed Breakfast (25% RMR)

LFPQ

Lunch

Dinner

-5 15 60 120 180 190 195 210 225 240 245 255 275 300 360 420 480 500 540 600

Estimated Time (minutes)
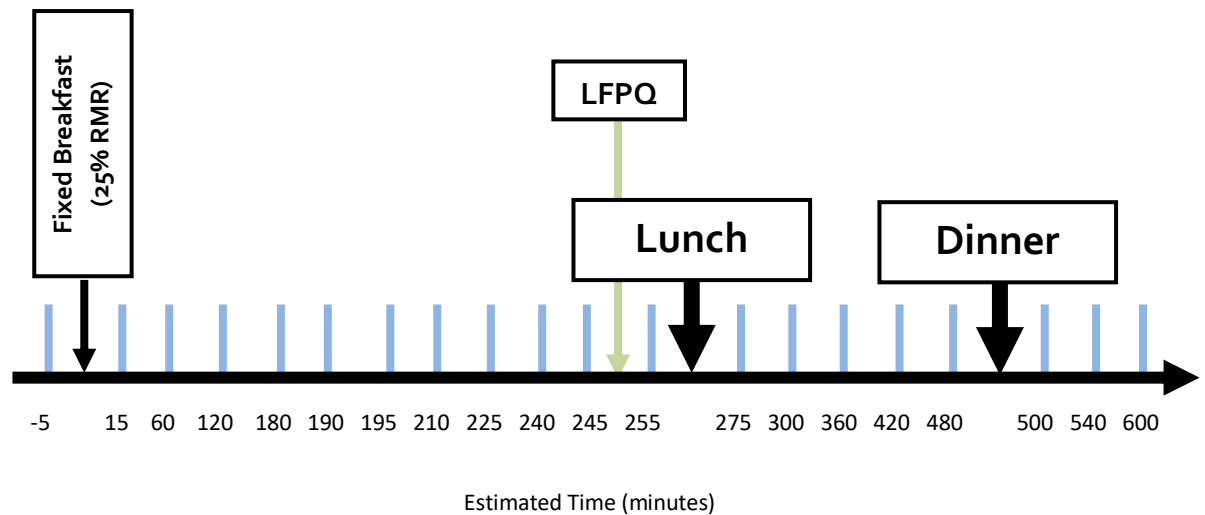
Figure 4.2. Schematic representation of the experimental session - Study 1b.

4.3.5 Data Analysis

Data was analysed using Statistical Programme for Social Sciences (SPSS) Version 22. Data for Study 1a and Study 1b has been analysed and reported separately. Reliability of the Satiety Quotient as a measure of satiety responsiveness was assessed by comparing Satiety Quotient across experimental sessions using Pearson correlation coefficients. Pearson correlation coefficients were also used to assess the relationship between physiological, psychological and behavioural variables and the Satiety Quotient. Participants were then categorised and characterised according to individual satiating efficiency. Average SQ for the 105-minute period following breakfast and a tertile split were used to identify high and low cut off points. Independent t-tests were used to compare scores on physiological, psychological and behavioural measures for the high and the low satiety phenotype. To assess the effect of satiety responsiveness on subjective appetite sensations a number of Mixed ANOVAs were conducted, with time as the within subjects factor and satiety phenotype as the between subjects factor. Independent t-tests were using to examine the effect of satiety responsiveness on ad libitum energy intake and food hedonics (liking and wanting and food craving). For all analyses an α-level of .05 was used to determine statistical significance. Where appropriate Greenhouse-Geisser probability levels were used to adjust for non-sphericity. Where significant effects were obtained post hoc analyses, with a Bonferroni correction for multiple comparisons were conducted. Cohen's d was used as a measure of effect size.

4.4 Results

4.4.1 Participant Characteristics

Participant characteristics of age, anthropometrics, body composition and eating behaviour traits for the overall sample for Study 1a (n, 31, age: 27.1 ± 10.6 years, BMI: 25.1 ± 2.9 kg/m^2) and Study 1b (n, 30, age: 28.2 ± 11.6 years, BMI: 24.8 ± 3.3 kg/m^2) are shown in Table 4.5.

Table 4.5. Mean (standard deviation) and range for age, anthropometric measures, body composition, TFEQ restraint, disinhibition, hunger and binge eating score.

	Study 1a		Study 1b	
	Mean (SD)	Range	Mean (SD)	Range
Age (years)	27.1 (10.6)	18.0 – 55.0	28.2 (11.6)	18.0 – 55.0
Weight (kg)	74.3 (12.6)	54.6 – 100.0	71.9 (13.1)	54.6 – 100.5
BMI (kg/m^2)	25.1 (2.9)	23.0 – 32.0	24.8 (3.3)	23.0 – 32.0
Waist (cm)	86.8 (9.9)	71.7 – 118.0	85.8 (9.2)	71.7 – 118.0
Fat mass (kg)	17.7 (9.4)	2.6 – 40.9	18.1 (8.5)	2.6 – 40.9
Fat free mass (kg)	56.7 (12.3)	38.5 – 85.5	53.8 (11.9)	38.5 – 78.4
Body fat (%)	23.6 (10.9)	3.6 – 47.2	24.6 (10.3)	3.6 – 43.0
TFEQ Restraint	8.3 (4.7)	1.0 – 17.0	8.7 (5.1)	1.0 – 17.0
TFEQ Disinhibition	6.7 (3.4)	0.0 – 17.0	6.2 (2.8)	0.0 – 13.0
TFEQ Hunger	6.1 (3.6)	1.0 – 12.0	5.4 (3.3)	1.0 – 12.0
Binge Eating Score	6.6 (3.4)	1.0 – 14.0	6.1 (3.4)	1.0 – 14.0

4.4.2 Reliability of the SQ as a Measure of Satiety Responsiveness

In Study 1a there was a significant correlation between SQ for hunger [$r = 0.63$, $p<0.001$], fullness [$r = 0.64$, $p<0.001$], desire to eat [$r = 0.63$, $p<0.001$], prospective consumption [r 0.58, $p<0.01$] and the mean of all four appetite sensations [$r = 0.49$, $p<0.01$] at visit 1 and visit 2. In Study 1b there was a significant correlation between SQ for hunger [$r = 0.61$, $p<0.001$], fullness [$r = 0.71$, $p<0.001$], desire to eat [$r = 0.68$, $p<0.001$], prospective consumption [$r = 0.59$, $p<0.01$] and the mean of all four appetite sensations [$r = 0.70$, $p<0.001$] at visit 1 and visit 2. Figure 3 shows the association between SQ for hunger between experimental visits for Study 1a and 1b.

(a)
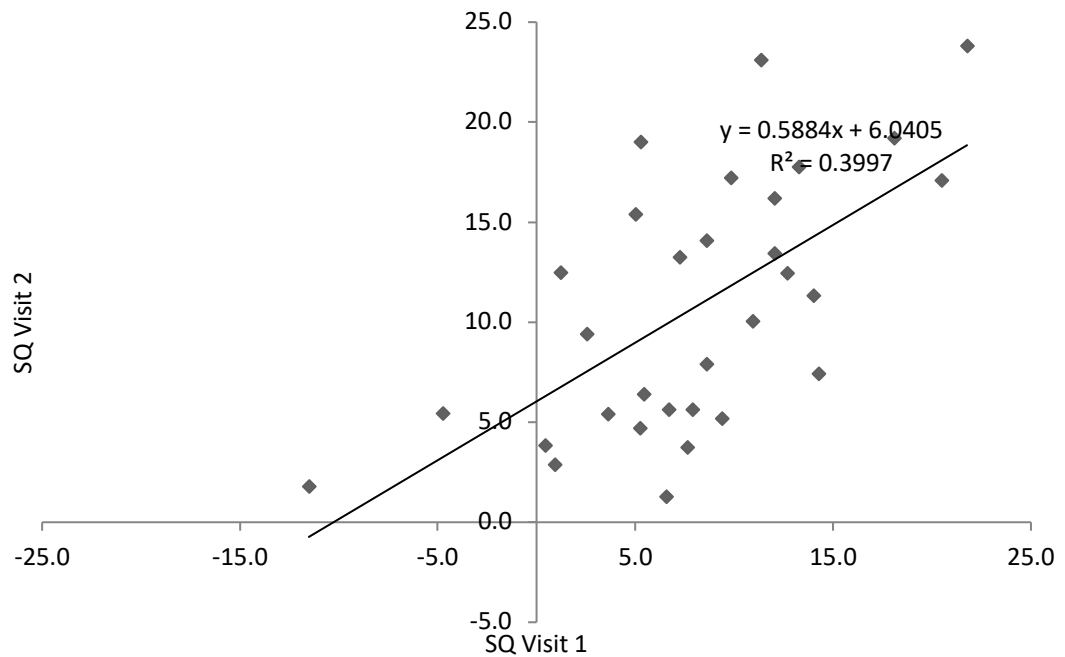
(b)
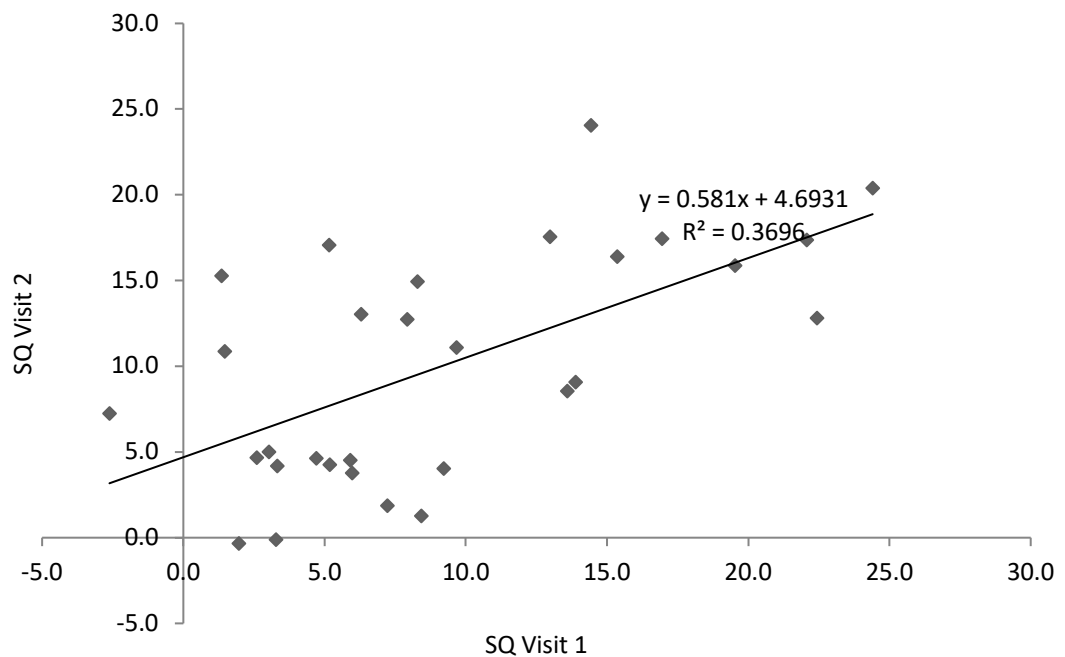
Figure 4.3. Correlation between SQ Hunger (Study 1a (a) Study 1b (b)) at visit 1 and 2.

4.4.3 Validity of the Satiety Quotient as a Marker of Susceptibility

In Study 1a average SQ for hunger was negatively associated with TFEQ hunger [r -0.47, p<0.05] and ad libitum energy intake [r -0.42, p<0.01] and positively associated with average baseline hunger rating [r 0.57, p<0.01]. Similarly, in Study 1b average SQ for hunger was positively associated with average baseline hunger rating [r 0.57, p<0.01]. In

addition, in Study 1b average SQ for hunger was positively associated with age [r 0.55, p<0.01] and negatively associated with resting metabolic rate [r -0.42, p<0.05]. These associations suggest low SQ may be associated with risk for overconsumption. To explore these further we categorised participants into satiety phenotypes.

4.4.4 Categorisation and Characterisation of Satiety Phenotypes

To categorise participants according to their individual satiety efficiency, satiety quotient for hunger for the 105-minute period following breakfast was calculated and an average across visits determined. Average SQ was stratified according to sex and then a tertile split was used to calculate high and low cut-off points. In Study 1a, the low satiety phenotype were identified as those who had a SQ ≤ 5.9 for males and ≤ 6.0 for females whereas the high satiety phenotype were identified as those who had a SQ ≥ 10.5 for males and ≥ 17.2 for females. Eleven participants were not categorised as either high or low satiety responders and were not included in any subsequent analyses. In Study 1b, low satiety phenotype were identified as those who had a SQ ≤ 4.5 for males and ≤ 6.2 for females whereas the high satiety phenotype were identified as those who had a SQ ≥ 10.3 for males and ≥ 17.6 for females. Ten participants were not categorised as either high or low satiety responders and were not included in any subsequent analyses. Table 6 shows characteristics for the low and the high satiety phenotype for Study 1a and 1b.

Table 4.6. Mean (SD) SQ, appetite sensations, age, anthropometrics, body composition, resting metabolism and eating behaviour traits for the low and high satiety phenotypes.

	Study 1a		Study 1b	
	LSP (n, 10)	HSP (n, 10)	LSP (n, 10)	HSP (n, 10)
SQ (mm/kcal)[1]	3.0 (3.4)***	15.1 (4.0)***	3.7 (1.7)***	16.1 (4.0)***
Hunger (mm)[1]	54.7 (17.7)**	72.6 (8.2)**	46.2 (21.6)**	74.2 (9.8)**
Desire to Eat (mm)[1]	56.0 (16.1)	68.8 (19.4)	50.6 (20.8)**	71.7 (9.1)**
Fullness (mm)[1]	24.7 (15.2)	14.3 (10.8)	25.1 (15.2)*	11.2 (6.9)*
Age (years)	24.2 (9.5)	31.1 (11.9)	24.7 (9.8)*	37.8 (12.7)*
Weight (kg)	74.8 (13.8)	73.5 (12.6)	71.6 (12.4)	71.7 (13.5)
BMI (kg/m^2)	25.2 (2.8)	24.3 (2.1)	24.7 (3.6)	24.9 (2.5)
Waist (cm)	86.7 (10.5)	84.7 (7.8)	83.3 (7.8)	86.8 (7.2)

Fat mass (kg)	15.7 (6.7)	16.6 (11.9)	16.2 (7.4)	18.9 (8.3)
Fat free mass (kg)	59.1 (12.3)	56.8 (15.5)	55.4 (12.5)	52.7 (13.7)
Body fat (%)	21.0 (7.5)	22.9 (14.7)	22.6 (8.5)	25.2 (12.6)
Resting Metabolic Rate (kcal)	1810.3 (325.9)	1663.4 (354.5)	1650.2 (258.3)	1528.3 (275.2)
TFEQ Restraint	7.3 (4.6)	8.4 (4.9)	7.7 (5.1)	7.4 (5.1)
TFEQ Disinhibition	6.9 (4.1)	5.8 (2.3)	6.9 (3.1)	5.1 (2.7)
TFEQ Hunger	7.7 (3.1)*	3.8 (3.8)*	6.0 (4.1)	4.0 (2.1)
Binge Eating Score	7.1 (2.6)	5.5 (3.7)	5.0 (2.9)	5.9 (3.0)

Note: [1]Average collapsed across study visits; *$p<0.05$; **$p<0.01$; ***$p<0.001$.

As expected the low satiety phenotype had a lower SQ across the study visits compared to the high satiety phenotype (t (18) = 7.22, $p<0.001$, d = 3.3, t (12) = 8.98, $p<0.001$, d = 4.3, Study 1a & 1b respectively). The low satiety phenotype reported lower baseline hunger (t (13) = 2.91, $p<0.01$, d = 1.3) and had greater TFEQ Hunger scores (t (16) = 2.37, $p<0.05$, d = 1.1) compared to the high satiety phenotype in Study 1a. Similarly, in Study 1b the low satiety phenotype reported lower baseline hunger (t (13) = 3.73, $p<0.01$, d = 1.8), desire to eat (t (18) = 2.94, $p<0.01$, d = 1.4) and greater fullness (t (13) = 2.63, $p<0.05$, d = 1.2) compared to the high satiety phenotype. Furthermore, the low satiety phenotype were younger than the high satiety phenotype (t (18) = 2.58, $p<0.05$, d = 1.2).

4.4.5 Subjective Appetite Sensations

There was a main effect of time on ratings of hunger, desire to eat, prospective consumption and fullness in Study 1a (F (5, 95) = 60.9, $p<0.001$; F (6, 113) = 43.0, $p<0.001$; F (5, 93) = 54.6, $p<0.001$; F (6, 111) = 50.8, $p<0.001$; respectively) and Study 1b (F (5.3, 94.8) = 44.8, $p<0.001$; F (5.8, 103.8) = 39.7, $p<0.001$; F (4.4, 78.3) = 41.8, $p<0.001$; F (6.1, 110.4) = 51.7, $p<0.001$; respectively). In addition, in Study 1a and Study 1b, there was an interaction between time and satiety phenotype for hunger (F (5, 95) = 5.76, $p<0.001$; F (5.3, 94.8) = 3.57, $p<0.01$, respectively) and fullness (F (6, 111) = 3.94, $p<0.01$; F (6.1, 110.4) = 2.98, $p<0.01$, respectively), as well as desire to eat (F (6, 113) = 2.84, $p<0.05$) and prospective consumption (F (5, 93) = 3.33, $p<0.01$) in Study 1a.

(a)

(b)
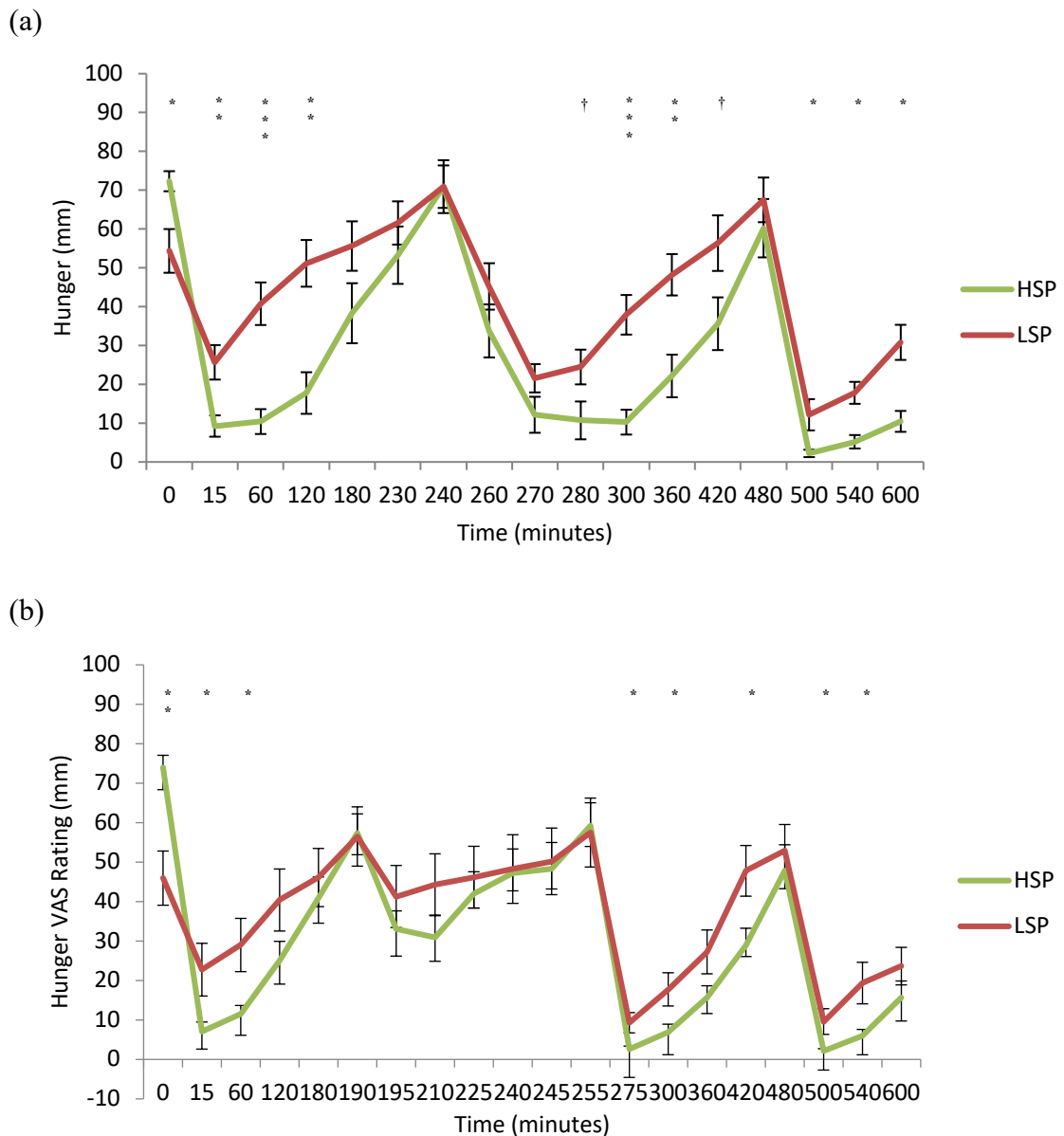
Figure 4.4. Ratings of hunger ((a) Study 1a (b) Study 1b) for the high and low satiety phenotype across the test day. Note: Ratings collapsed across study visits; *p<0.05, **p<0.01, ***p<0.001, †p=0.05.

Furthermore, there was a main effect of satiety phenotype, analyses revealed that the low satiety phenotype reported significantly higher levels of hunger (F (1, 18) = 7.09, p<0.05), desire to eat (F (1, 18) = 5.59, p<0.05) and prospective consumption (F (1, 18) = 7.58, p<0.05) and lower levels of fullness (F (1, 18) = 6.19, p<0.05) compared to the high satiety phenotype in Study 1a. Similarly, in Study 1b the low satiety phenotype reported significantly lower levels of fullness [F (1, 18) = 10.1, p<0.01] across the day, compared to the high satiety phenotype. Post hoc analyses revealed that the low satiety phenotype had significantly lower baseline hunger across both Study 1a and 1b (t (13) = 2.91, p<0.05, d = 1.3; t (12.6) = 3.73, p<0.01, d = 1.8, respectively) compared to the high

satiety phenotype. Figures 4 - 7 show subjective appetite sensations across the test day for the high and the low satiety phenotype, for both Study 1a and Study 1b.

(a)
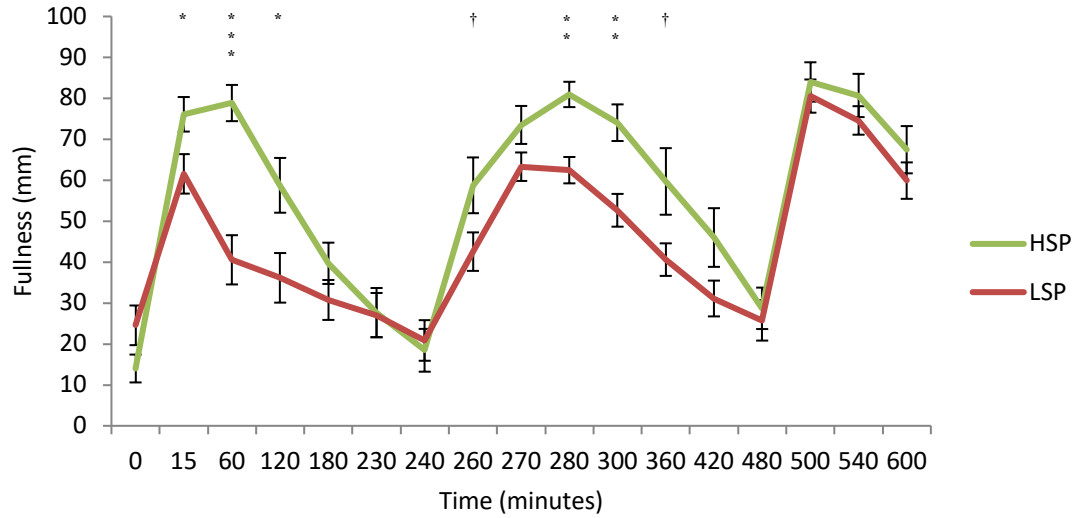
(b)
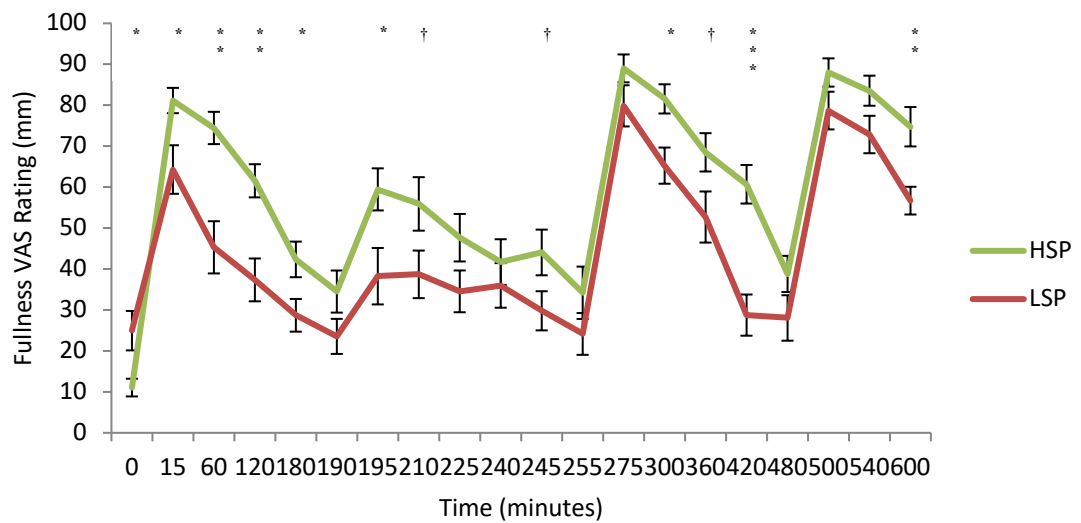
Figure 4.5. Ratings of fullness ((a) Study 1a (b) Study 1b) for the high and low satiety phenotype across the test day. Note: Ratings collapsed across study visits; *p<0.05, **p<0.01, ***p<0.001, †p=0.05.
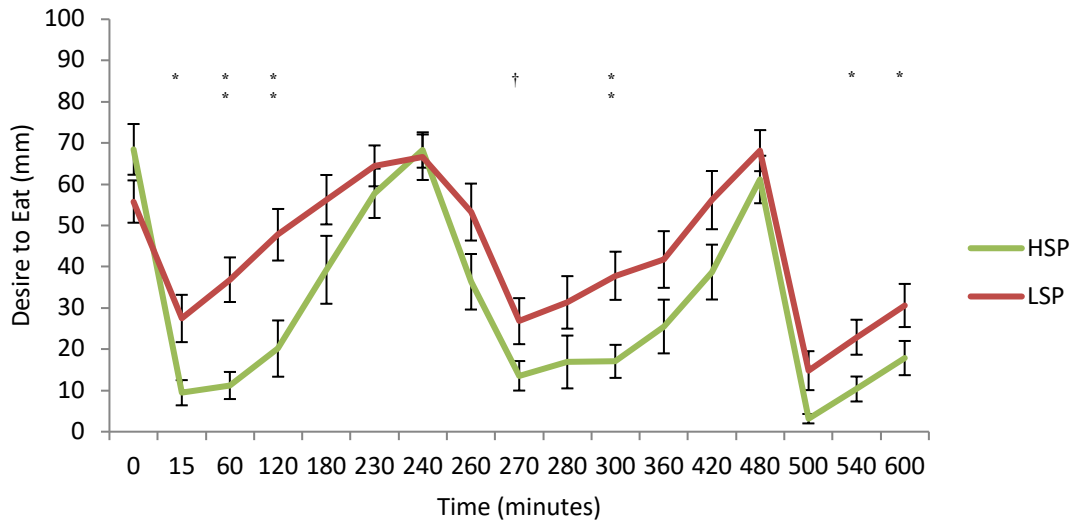
Figure 4.6. Ratings of desire to eat (Study 1a) for the high and low satiety phenotype across the test day. Note: Ratings collapsed across study visits; *p<0.05, **p<0.01, ***p<0.001, †p=0.05.
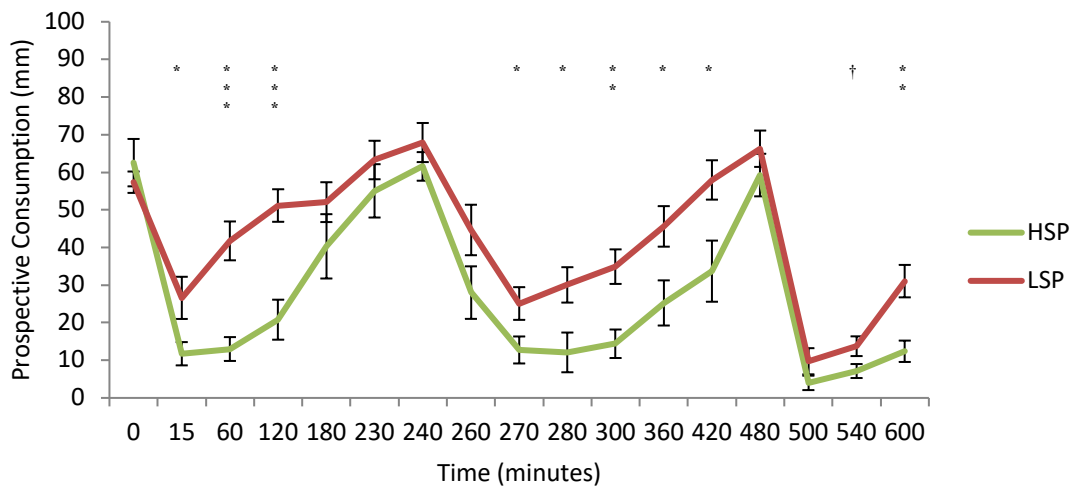
Figure 4.7. Ratings of prospective consumption (Study 1a) for the high and low satiety phenotype across the test day. Note: Ratings collapsed across study visits; *p<0.05, **p<0.01, ***p<0.001, †p=0.05.

4.4.6   Ad Libitum Energy Intake

Figure 8 shows energy intake from the ad libitum test meal served at lunch (Study 1b) and dinner (Study 1a and Study 1b) for the low and the high satiety phenotype. Overall, the low satiety phenotype consumed more energy compared to the high satiety phenotype, however these differences did not reach statistical significance (t (12.2) = .872, p = .39; t (18) = 0.68, p = .51; t (18) = 1.50, p = .15, respectively).

(a)

(b)
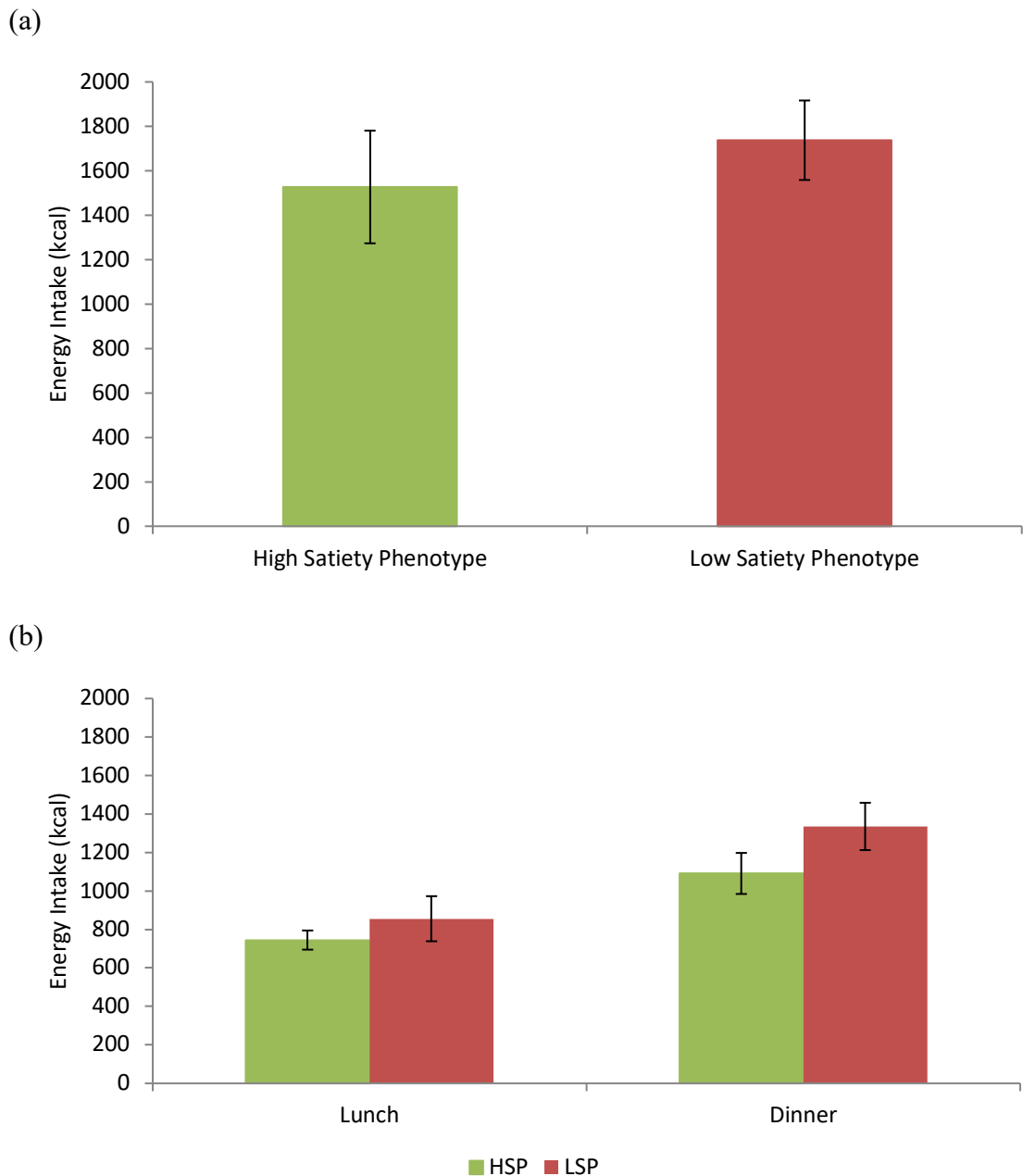
Figure 4.8. Energy intake (kcal) from the ad libitum test meals ((a) Study 1a (b) Study 1b) for the low and the high satiety phenotype. Note: Average energy intake across visits.

4.4.7 Food Hedonics

4.4.7.1 Explicit Liking and Implicit Wanting Fat Appeal Bias

Analysis of explicit liking and implicit wanting fat appeal bias in both Study 1a and Study 1b revealed that neither liking ($t(18) = 0.18$, $p = .86$; $t(18) = .108$, $p = .92$, respectively) or wanting ($t(18) = 0.06$, $p = .95$; $t(18) = .602$, $p = .56$, respectively) for high fat foods, differed between the low and the high satiety phenotype.

4.4.7.2 Explicit Liking and Implicit Wanting Taste Appeal Bias

Analysis of implicit wanting taste appeal bias in Study 1a revealed that the low satiety phenotype had a greater bias for sweet foods compared to the high satiety phenotype [t (18) = 2.21, p<0.05, d = 1.0]. There were however no difference in explicit liking taste appeal bias and implicit wanting taste appeal bias (t (18) = .443, p = .66; t (18) = .518, p = .61, respectively) between the low and the high satiety phenotype in Study 1b.
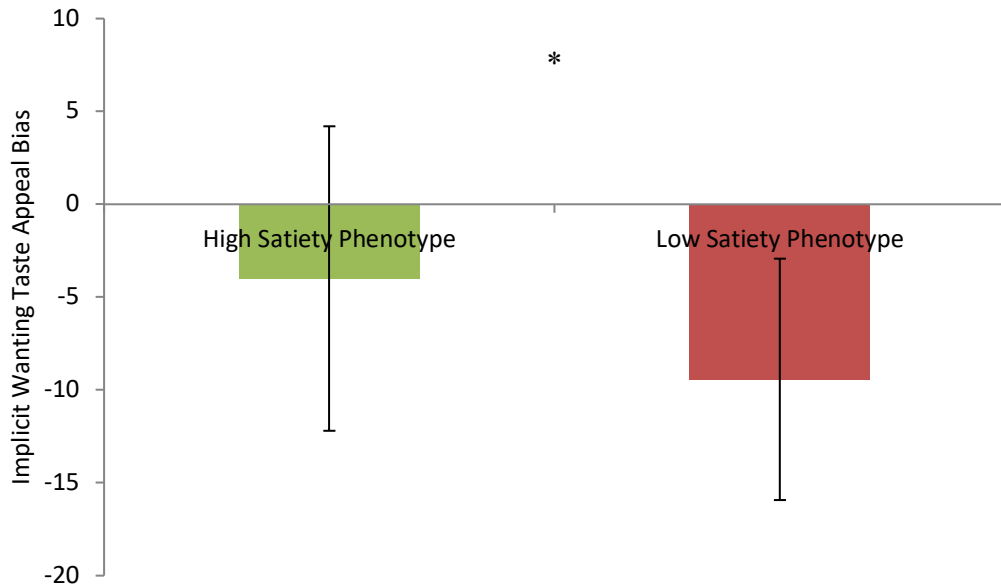
Figure 4.9. Implicit wanting taste appeal bias for the high and the low satiety phenotype.

4.4.7.3 Craving for Food

Figure 4.10. Craving control, craving for sweet, craving for savoury and positive mood scores on the CoEQ for the high and low satiety phenotype (Study 1a). Note; *p<0.05.

The low satiety phenotype scored lower on the Craving Control subscale of the CoEQ (t (17) = 2.52, p<0.05, *d* = 1.2) in Study 1a, compared to the high satiety phenotype. There were no differences on the Craving for Sweet, Craving for Savoury or Positive Mood subscales of the Control of Eating Questionnaire (t (17) = 0.26, p = .79; t (17) = 0.99, p = .334; t (17) = 1.41, p = .18, respectively). Analysis of craving for food in Study 1b revealed no differences between the high and the low satiety phenotype on Craving Control (t (16) = .459, p = .65), Craving for Sweet (t (16) = .439, p = .67), Craving for Savoury (t (16) = .211, p = .84) and Positive Mood (t (16) = 1.62, p = .12) subscales.

4.5   Discussion

The first aim of the current study was to determine the reliability and the validity of the satiety quotient as a measure of satiety responsiveness. The second aim was to explore what makes individuals who are identified, using the satiety quotient, as low or high satiety responders different; considering a range of behavioural, psychological, physiological and metabolic factors. The final aim was to examine subjective appetite sensations for hunger, fullness, desire to eat and prospective consumption for individuals identified as low or high satiety responders. The current study found that the satiety quotient is a reliable and valid measure of satiety responsiveness. The satiety quotient for all appetite sensations (hunger, fullness, desire to eat and prospective consumption) showed good reliability. In addition, satiety quotient was associated with a number of risk factors for overconsumption. The low satiety phenotype displayed greater TFEQ Hunger, greater wanting for sweet foods and lower control over food cravings. Furthermore, the low satiety phenotype are characterised by an impaired capacity to detect appetite sensations and reduced intensity and duration of post ingestive activity.

The current study demonstrates that the satiety quotient is a reliable marker of satiating efficiency. We found that using the satiety quotient, it is possible to identify individuals who reliably experience weak satiating efficiency following a standardised test meal. In the current study, correlation coefficients for SQ, for all appetite sensations, across the study visits ranged between 0.49 – 0.64 (Study 1a) and 0.59 – 0.70 (Study 1b). Previous research has demonstrated the usefulness of individual appetite sensations to predict overall energy intake (Drapeau et al., 2005) and the ability of the satiety quotient to predict individual energy intake as well as reliably measure satiety responsiveness to determine a low satiety phenotype (Drapeau et al., 2007; Drapeau et al 2013). The findings of the current study provide additional support for the use of the satiety quotient

as a measure of satiety responsiveness and means of identifying the low satiety phenotype. Here we have demonstrated the reliability of the satiety quotient across both study visits and different studies. It is worth noting previous research has used fullness/mean of appetite ratings in the calculation for SQ (Drapeau et al., 2005; Drapeau et al., 2007; Drapeau et al 2013). While we were able to demonstrate good consistency between all SQ, here we have used Hunger ratings in the calculation for satiety quotient.

The current study found that low satiety responsiveness, determined using the satiety quotient, was associated with greater TFEQ hunger, ad libitum energy intake (Study 1a) and resting metabolic rate as well as age (Study 1b). Furthermore, low satiety responsiveness was associated with lower baseline ratings of hunger. These associations suggest that low satiety responsiveness may be associated with risk for overconsumption. To explore these further we categorised participants according to satiety phenotypes.

We found that the low satiety phenotype have greater TFEQ Hunger scores compared to the high satiety phenotype (Study 1a). Previous research has shown that the low satiety phenotype are characterised by psychological factors linked with overeating such as anxiety, greater night eating symptoms and external hunger (Drapeau et al., 2013). In addition as association between trait disinhibition and satiety responsiveness (Barkeling et al., 2007). Therefore providing further support for the notion that low satiety phenotype are characterised by distinct behavioural and psychological characteristics. Furthermore, the association between SQ and energy intake is consistent with the findings of previous research (Drapeau et al 2007; Drapeau et al 2013). However, while the low satiety phenotype consumed more energy from the ad libitum test meals compared to the high satiety phenotype, these differences did not reach statistical significance (Study 1a and Study 1b). Another finding from the current study was that the low satiety phenotype were younger than the high satiety phenotype (Study 1b). This finding is not consistent with any of the existing research in this area. No differences in age have previously been reported. It therefore warrant further investigation. It could be that satiety responsiveness develops with age as a result of experience and/or learning.

Analysis of implicit wanting taste appeal bias revealed that the low satiety phenotype had a greater bias for sweet foods compared to the high satiety phenotype. In addition, the low satiety phenotype scored lower on the Craving Control subscale of the CoEQ, which means they reported feeling lower control over their cravings. The tendency to experience greater food cravings has been associated with greater BMI (Franken & Muris 2005; White et al 2002). These findings provide support to the existence of psychological

differences between the low and the high satiety phenotype, and suggest that the low satiety phenotype is characterised by hedonic risk factors for overconsumption.

Furthermore, the low satiety phenotype reported lower baseline hunger. Whilst unexpected, it may be that after a period of fasting the people with the low satiety phenotype are poor at detecting their appetite sensations, which is consistent with the findings of Barkeling and colleagues (2007). In addition the low satiety phenotype reported significantly greater levels of hunger, desire to eat and prospective consumption and lower levels of fullness across the course of the test session compared to the high satiety phenotype. Taken together these findings suggest that the low satiety phenotype have an impaired capacity to detect appetite sensations and a reduced intensity and duration of post ingestive activity. This distinct profile of hunger suggests that the consumption of food exerts a weaker suppression of hunger in the early postprandial period in the low satiety phenotype. Furthermore, it is interesting to see hunger recovers faster in the low satiety phenotype in the late postprandial period compared to the high satiety phenotype. Possible mechanisms such as release of appetite related peptides or rate of gastric emptying may be implicated and could be considered in future research.

In conclusion, the satiety quotient is a reliable measure of satiety responsiveness, that can be used to identify individuals who reliably experience a weak or strong satiating efficiency. The low satiety phenotype are characterised by distinct behavioural and psychological characteristics that may increase their susceptibility to overeating.

Chapter 5

Assessment of the Reliability of the Satiety Quotient in Response to Macronutrient Manipulation

5.1   Abstract

Background: It is well established that different macronutrients exert different effects on appetite control, specifically on the processes of satiation and satiety. The current study examined the effects of macronutrient manipulation, in the form of ad libitum and fixed energy meals that varied in fat and carbohydrate content on the Satiety Quotient.

Method: In a randomised, counterbalanced, repeated measures design, forty-six individuals (age: 43.2±7.5 years; BMI: 30.5±3.8 kg/m²) completed two separate laboratory test meal days. Participants consumed high fat/low carbohydrate (HF; >50% energy from fat) or low fat/high carbohydrate (LF; <25% energy from fat) foods. Satiety was measured using subjective appetite ratings and satiation was assessed using energy intake at ad libitum meals. Ratings of subjective hunger were used to calculate the SQ.

Results: There was no effect of the HF/LF test meal days on subjective hunger across the day. However, ad libitum energy intake was lower in the LF condition compared with the HF condition. Furthermore, Satiety Quotient was greater following ad libitum and fixed energy meals during the LF test day. Finally, Satiety Quotient as a measure of individual satiety responsiveness was consistent across the HF and LF test meals.

Conclusion: The present study found that the SQ, as a measure of satiety responsiveness, is sensitive to different macronutrient manipulations. However, despite variability in the SQ response to the different macronutrients, intraindividual variability in SQ was low. These findings support the use of the SQ as a reliable measure of satiety responsiveness.

5.2   Introduction

It is well established that different macronutrients, exert different effects on appetite control, specifically on the processes satiation and satiety (Blundell et al 1996; Holt et al

1995). In a review by Stubbs and colleagues, it was noted that different macronutrients exerted a hierarchal effect on satiety, with proteins exerting the greatest effect (i.e. being the most satiating), followed by carbohydrates and then fat (Stubbs et al., 2000). The impact of individual macronutrients on satiety is usually measured in experimental studies using a preload design (Gerstein et al., 2004). The effects of fat and carbohydrate on satiety are well documented (Blundell et al 1996; Blundell et al 1993). Specifically, studies conducted by Blundell and colleagues found that high-fat foods have a weak effect on satiation and satiety compared with carbohydrate.

Holt (1995) calculated a satiety index score by dividing the area under the curve for the satiety response to commonly consumed test foods by the study group mean satiety area under the curve for the satiety response to a standardised food (i.e. white bread) and then multiplying by 100. They found that energy dense/fat rich foods had a lower satiety index score compared to foods that were high in protein, fibre or water content. Additional support is provided for the notion that foods of equal energy can have distinct effects on satiety if macronutrient compositions differ. Women whose diet was modified to be high in protein and carbohydrate reported higher levels of satiety compared to where the diet was high in fat, despite the two being matched for energy content (Westerterp-Plan et al 1999). Consistent with these findings, Buckland, Stubbs and Finlayson (2015) examined the perceived satiety value of 100 different foods. They found that, when perceived energy content was controlled for, higher perceived satiety values were associated with lower energy density, lower percentage fat and higher percentage protein.

Additional research has taken the concept of the differing effect of macronutrients on satiety further and considered individual differences in the satiety response to fat and carbohydrate. For example, Rolls and colleagues (Rolls et al., 2004) examined responses to fat and carbohydrate preloads in participants differing in body weight, sex and dietary restraint and found that obesity, being female and being high in dietary restraint were related to insensitivity to the satiating efficiency of fat. Similarly, Blundell et al (2005) found that habitual high fat consumers were relatively insensitive to satiety signals generated by fat consumption. Further to this, Chambers & Yeomans (2011) found that individuals scoring high for Disinhibition consumed more energy at a snack test meal than those with low Disinhibition, but only following a high carbohydrate breakfast.

Less is known about macronutrient manipulation in the low satiety phenotype. However, a study by Hopkins and colleagues (2016) reported a strong effect of macronutrient composition on satiety, as indicated by greater postprandial SQ scores, following both

ad libitum and isoenergetic test meals. This would suggest that SQ is a useful measure of satiety, that is sensitive to macronutrient manipulations. However, it remains to be established whether SQ is a consistent and reliable measure of individual satiety responsiveness across these macronutrient manipulations. In the previous study in the current thesis, it was established that SQ is a reliable and consistent measure of satiating efficiency. We found that by using the satiety quotient it was possible to identify individuals who reliably experienced a strong or weak satiating efficiency following a standardised test meal. Research conducted prior to this demonstrated that despite high interindividual variability in SQ, intraindividual variability is low (Drapeau et al., 2007). Furthermore, a study by Drapeau and colleagues demonstrated good reproducibility of the SQ when measurements were repeated 2-4 weeks apart (Drapeau et al., 2012). Taken together these findings suggest that the SQ represents a stable individual marker for satiety efficiencies that can be used to measure satiety responsiveness. However, previous studies have only assessed the consistency of SQ as a measure of satiety responsiveness using test meals matched for both calories and macronutrients.

5.2.1 Study Aims

The current study aimed to examine the effect of macronutrient manipulation (high fat vs. low fat) on the satiety quotient. In addition, it aimed to determine the extent to which the SQ was consistent within individuals across the high fat and low fat test conditions.

5.3 Method

5.3.1 Participants

Forty-six participants (age: 43.2±7.5 years; BMI: 30.5±3.8 kg/m²) were recruited via a University of Leeds email distribution list, which staff, students and members of the public are able to sign up to. Eligibility was determined using an online screening questionnaire. The inclusion criteria for the study was healthy male or female, aged between 18-55 years with a BMI between 27-45 kg/m^2. Participants who were taking medication known to affect appetite, currently dieting to lose or maintain weight or had lost/gained a significant amount of weight in the previous six months (>5%), smokers and those who had significantly changed their physical activity patterns in the past 4 weeks (>150 mins per week) were excluded. Eligible participants were invited to a screening session to confirm eligibility and have the study presented to them. Participants

provided written informed consent and all research procedures were reviewed and approved by the University of Leeds, School of Psychology Ethics committee.

5.3.2 Design

The study followed a randomised, counterbalanced, repeated measures design. Each participant attended the Human Appetite Research Unit at the University of Leeds on three occasions: a screening and measures session and two experimental sessions. The experimental sessions differed in the macronutrient composition of all foods available, either high fat >50% energy from fat (HF) or low fat <25% energy from fat (LF). These visits were scheduled at least seven days apart and for all visits participants were required to fast from 10pm the evening before to ensure a standardise fasting state. Participants were also instructed not to consume alcohol or engage in physical activity for 24-hours and not to consume caffeine for 12-hours prior to the sessions. Compliance with these instructions was assessed at the beginning of each session by self-report. During the experimental sessions participants consumed their breakfast, lunch and dinner in the research unit. Participants were free to leave the research unit in between the meals but were instructed not to eat or drink anything besides water. Ratings of subjective appetite were taken every 60 minutes throughout the day using a validated hand-held Electronic Appetite Rating System (Gibbons, Caudwell, Finlayson, King & Blundell, 2011). Together these measures enabled the satiety quotient to be calculated.

5.3.3 Measures

All measures were conducted within the Human Appetite Research Unit (HARU) at the University of Leeds; except the screening questionnaire which was completed online.

5.3.3.1 Online Screening Questionnaire

An online screening questionnaire was used to identify eligible participants based on the inclusion and exclusion criteria. Participants who met the criteria were sent a copy of the participant information sheet and invited to a screening and measures session.

5.3.3.2 Resting Metabolic Rate

Resting metabolic rate was measured using an indirect calorimeter fitted with a ventilated hood (GEM; Nutren Technology Ltd). Participants' RMR was assessed during the measures session. This measure is described in more detail in Chapter 3.

5.3.3.3 Anthropometrics and Body Composition

Standing height was measured to the nearest 0.5cm using a stadiometer, body weight was measured to the nearest 0.1kg using an electronic balance and waist circumference was measured at the participants' naval after expiration. Body composition (fat mass, fat free mass and percentage body fat) was assessed using air plethysmography (BodPod, Concord, CA, USA). Anthropometric and body composition measures were conducted during the measures session and are described in more detail in Chapter 3.

5.3.3.4 Eating Behaviour Questionnaires

Participants completed the Three Factor Eating Questionnaire (TFEQ; Stunkard & Messick, 1985) to assess levels of restraint, disinhibition and hunger and the Binge Eating Scale (BES; Gormally et al., 1982) to assess the severity of binge eating during the measures session. These questionnaires are described in more detail in Chapter 3.

5.3.3.5 Energy Intake

The test meals provided to participants during the experimental sessions consisted of either high fat (>50% energy from fat) or low fat (<25% energy from fat) foods. The foods provided on each day were as similar as possible whilst trying to keep the macronutrient composition largely different. See Table 1 below for details of the foods provided. Breakfast comprised of cornflakes, toast and scrambled eggs. Participants were instructed to consume as much or as little as they wanted, but to eat until they reached a comfortable level of fullness. The fixed energy lunch served to participants consisted of a cheese salad sandwich, crisps and cake. Lunch was served four hours following breakfast and participants were required to consume the lunch in its entirety. Energy intake was assessed at dinner using an ad libitum test meal. The dinner test meal consisted of pizza, garlic bread, salad, cake, biscuits and crisps and was served four hours following lunch. Participants were instructed to consume as much or as little as they wanted, but to eat until they reached a comfortable level of fullness. All food was weighed both pre and post consumption to the nearest 0.1g to determine energy intake.

Table 5.1. Foods provided to participants on the high and low fat test days.

Test Meal/Food Item	High Fat Foods	Low Fat Foods
	Energy Density (kcal/g)	
Breakfast		
Cornflakes	62.3	62.8

Milk	12.6	8.4
Toast	46.0	46.0
Eggs	75.3	25.1
Margarine	108.8	62.8
Sugar	67.0	67.0
Lunch		
Sandwich	62.8	46.0
Crisps	92.0	79.5
Cake	87.9	54.4
Dinner		
Pizza	50.2	37.7
Garlic Bread	75.3	46.0
Salad	25.1	4.2
Cake	87.9	46.0
Biscuits	96.2	8.4
Crisps	92.0	50.2
CHO (% energy)	37.7	72.4
Protein (% energy)	7.9	8.3
Fat (% energy)	54.4	19.3

5.3.3.6 Subjective Appetite Sensations

Ratings of hunger, fullness, desire to eat and prospective consumption were assessed using 100mm VAS presented on an Electronic Appetite Rating System. Ratings were completed at baseline, before and after each event in the procedure and at hourly intervals throughout the day. This measures are described in more detail in Chapter 3.

5.3.3.7 Satiety Quotient

Hunger VAS ratings were used to calculate SQ for the period following each test meal. The Satiety Quotient is described in more detail in Chapter 3.

$$SQ\ (mm/kcal) = \left(\frac{\text{rating before eating} - \text{mean of the post meal ratings}}{\text{energy content of the test meal (kcal)}} \right) \times 100$$

5.3.4 Procedure

For all sessions participants arrived at the research unit between 8.00-9.30am following an overnight fast. Participants were instructed not to consume alcohol or engage in physical activity for 24-hours and not to consume caffeine for 12-hours prior to the sessions. At the start of the screening and measures session participants eligibility was confirmed, they were then provided with a written and verbal explanation of the research requirements. They were given the opportunity to ask any questions before providing written informed consent. Height, weight, waist circumference, resting metabolic rate and body composition were measured. Participants also completed a number of eating behaviour questionnaires. For the experimental sessions, participants were shown to a research cubicle on arrival, where they completed a set of baseline VAS appetite ratings and consumed breakfast. Following breakfast a second set of VAS ratings were completed and participants were free to leave the research unit but were asked to return four hours later for lunch. During this time the EARS-II prompted completion of VAS rating at sixty minute intervals. Participants completed VAS ratings before and after the lunch test meal. Following lunch participants were once again free to leave the research unit but were asked to return four hours later for dinner. Participants continued to complete VAS ratings prompted by the EARS-II at sixty minute intervals while away from the research unit. Participants completed VAS ratings before and after the dinner test meal. Following the dinner test meal participants were free to leave, until the next experimental session. On completion of all study procedures participants received a written and verbal debrief and were compensated for taking part in the study. See Figure 1 for schematic representation of the procedure.

Estimated Time (minutes)
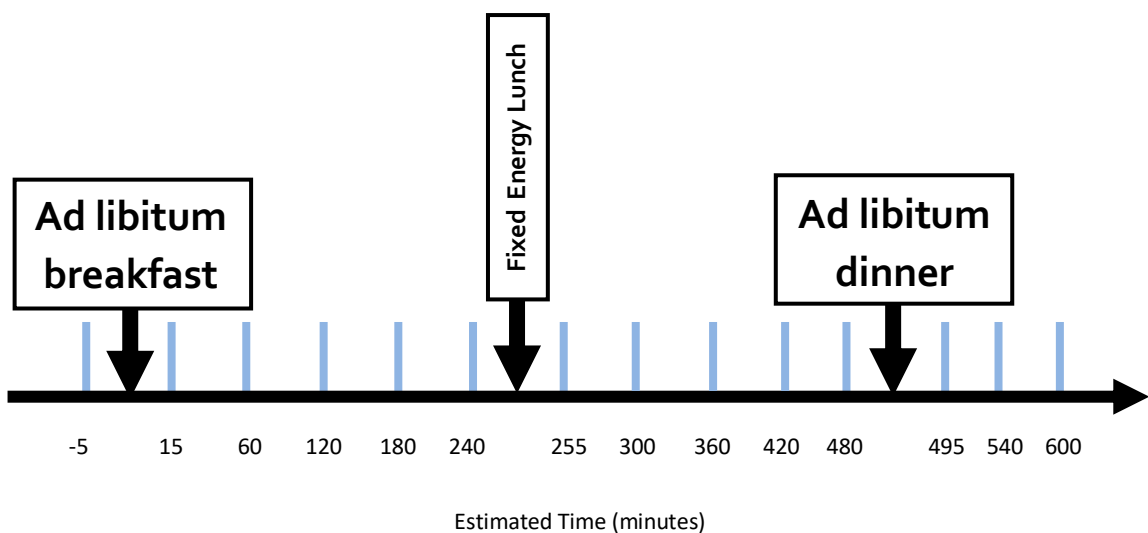
Figure 5.1. Schematic representation of the study procedure - experimental session. Blue vertical bars indicate where visual analogue scale appetite sensations were measured.

5.3.5 Data Analysis

Data was analysed using Statistical Programme for Social Sciences (SPSS) Version 22. A paired samples t-test was used to examine the difference between baseline subjective ratings of hunger on the high fat and low fat test days. The effect of macronutrient composition on subjective ratings of hunger was then assessed using a two-way repeated measures ANOVA (time x macronutrient). Paired samples t-tests were used to examine differences in ad libitum energy intake on the high fat and low fat test days. The effect of macronutrient composition on the Satiety Quotient was examined following each test meal using separate two-way repeated measures ANOVAs (time x macronutrient). Finally, the reliability of the SQ in response to the high and low fat foods was assessed using Pearson correlation coefficients. For all analyses an α-level of .05 was used to determine significance. Where appropriate Greenhouse-Geisser probability levels were used to adjust for non-sphericity. Where significant effects were obtained post hoc analyses, with a Bonferroni correction for multiple comparisons were conducted.

5.4   Results

5.4.1   Participant Characteristics

Characteristics of age, anthropometrics, body composition and eating behaviour traits for the overall sample (age: 43.2±7.5 years; BMI: 30.5±3.8 kg/m²) are show in Table 5.2.

Table 5.2. Mean (standard deviation) and range for age, anthropometric measures, body composition, TFEQ Restraint, Disinhibition, Hunger and Binge Eating Score.

	Mean (SD)	Range
Age	43.2 (7.5)	28 – 55
Weight (kg)	87.5 (14.3	61.6 – 134.3
BMI (kg/m²)	30.5 (3.8)	26.1 – 43.3
Waist (cm)	101.6 (10.6)	79.5 – 129.0
Fat mass (kg)	35.1 (9.2)	19.3 – 58.4
Fat free mass (kg)	52.5 (10.3)	33.5 – 75.8
Body fat (%)	40.0 (7.6)	23.1 – 54.6

RMR (kcal)	1694 (311.9)	1122.0 – 2365.6
TFEQ Restraint	7.5 (3.7)	2.0 – 15.0
TFEQ Disinhibition	8.3 (3.4)	3.0 – 14.0
TFEQ Hunger	5.4 (3.6)	1.0 – 14.0
Binge Eating Score	12.0 (7.0)	1.0 – 33.0

5.4.2 Appetite Sensations

There were no differences between baseline hunger ratings on the high fat and low fat test days ($t(45) = 0.17$, $p = .87$). Similarly, there were no differences in ratings of hunger immediately before the lunch and dinner test meals on the high fat and low fat test days ($t(45) = 1.28$, $p = .21$; $t(45) = 1.56$, $p = .13$ respectively). There was no effect of the high fat/low fat manipulation on subjective ratings of hunger. There was a main effect of time ($F(5,237) = 100.8$, $p<0.001$) but no effect of macronutrient composition ($F1,44) = 0.8$, $p = .374$) on ratings of hunger. There was also no interaction between time and macronutrient composition on ratings of hunger ($F(7, 308) = 1.4$, $p = .202$).
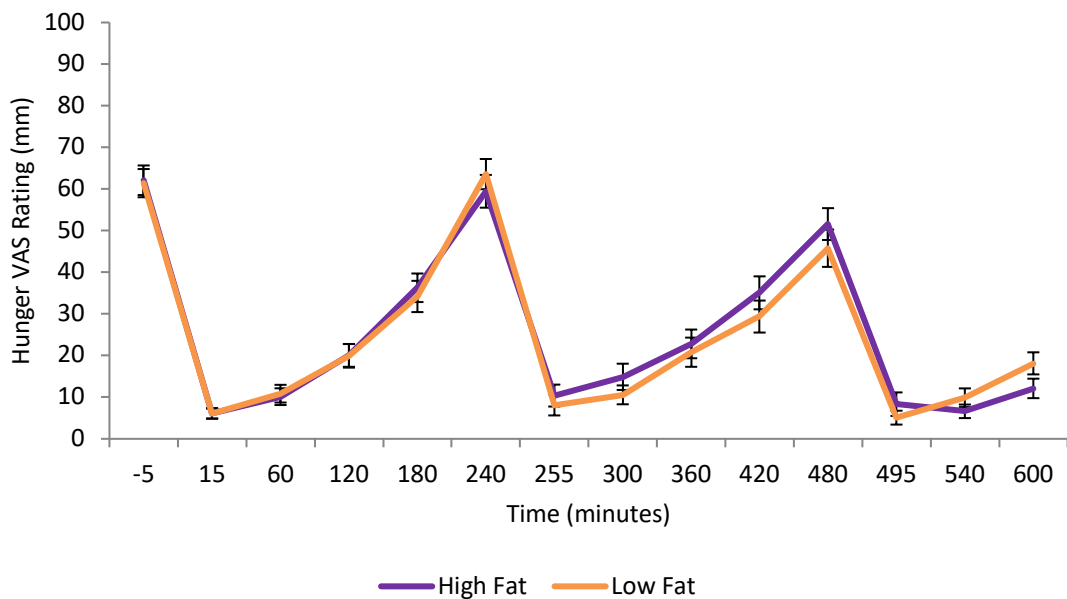
Figure 5.2. Subjective ratings of appetite (hunger) across the high fat/low fat test days.

5.4.3 Energy Intake

Figure 3 shows total energy intake as well as energy intake from each test meal on the high fat and low fat test days. Total energy intake was greater on the high fat compared to the low fat test day ($t(45) = 11.0$, $p<0.001$). Participants consumed significantly more

energy from both the high fat breakfast (t (45) = 6.5, p<0.001) and the high fat dinner (t (45) = 11.9, p<0.001) test meals compared to the equivalent low fat test meals.
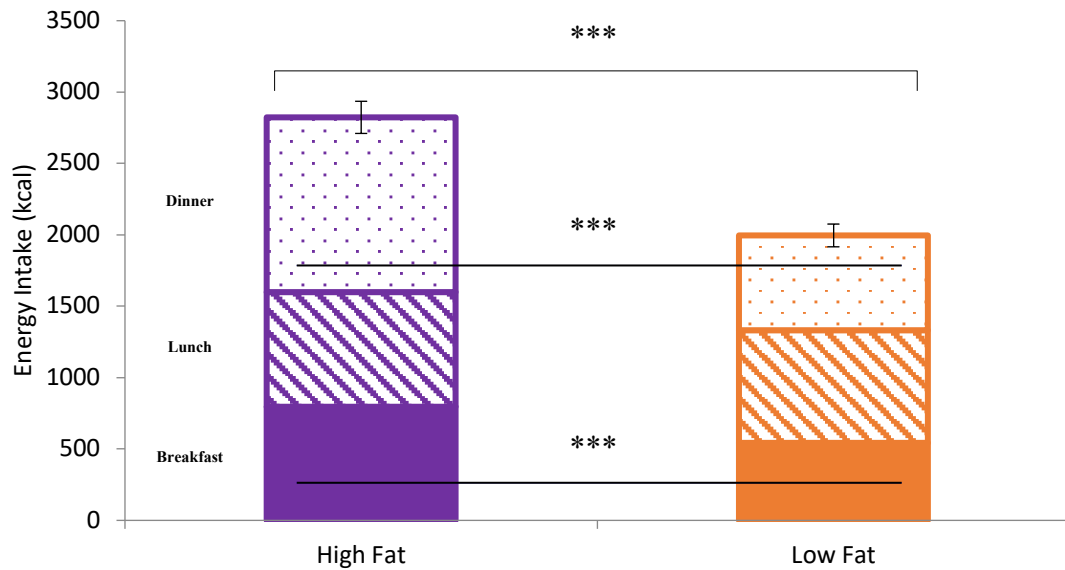
Figure 5.3. Energy intake (kcal) from the ad libitum (breakfast and dinner) and fixed energy (lunch) test meals on the high fat and low fat test days. Note: ***p<0.005.

5.4.4 Satiety Quotient in Response to High Fat and Low Fat Foods

5.4.4.1 Ad Libitum Breakfast

There was a significant effect of macronutrient composition on the Satiety Quotient following the consumption of the ad libitum breakfast meal (Figure 4). There was a significant main effect of time ($F_{(4,57)}$ = 283.9, p<0.001) and macronutrient composition ($F_{(1,45)}$ = 9.5, p<0.01). Furthermore, there was a significant interaction between time and macronutrient composition ($F_{(1,61)}$ = 8.3, p<0.01). SQ for the low fat breakfast was significantly higher than SQ for the high fat breakfast immediately after (p<0.01), and at 60 min (p<0.01), 120 min (p<0.01) and 180 min (p<0.05) post meal consumption.

5.4.4.2 Ad Libitum Dinner

There was also a significant effect of macronutrient composition on the Satiety Quotient following the consumption of the ad libitum dinner meal (Figure 5). There was a significant main effect of time ($F_{(1,53)}$ = 77.9, p<0.001) and macronutrient composition ($F_{(1,45)}$ = 7.7, p<0.01). Furthermore, there was a significant interaction between time and macronutrient composition ($F_{(1,57)}$ = 7.2, p<0.01). SQ for the low fat dinner was significantly higher than SQ for the high fat dinner immediately after (p<0.01), and at 60 min (p<0.01) and 120 min (p<0.05) post meal consumption.

5.4.4.3 Fixed Energy Lunch

Finally, there was an effect of macronutrient composition on the Satiety Quotient following the consumption of the fixed energy lunch meal (Figure 6). There was a significant main effect of time ($F_{(2,73)} = 213.9$, $p < 0.001$) and macronutrient composition ($F_{(1,45)} = 5.7$, $p < 0.05$). There was also a significant interaction between time and macronutrient composition ($F_{(2,80)} = 3.4$, $p < 0.05$). SQ for the low fat lunch was significantly higher than SQ for the high fat lunch at 60 min ($p < 0.05$), 120 min ($p < 0.05$) and 180 min ($p < 0.01$) post meal consumption.
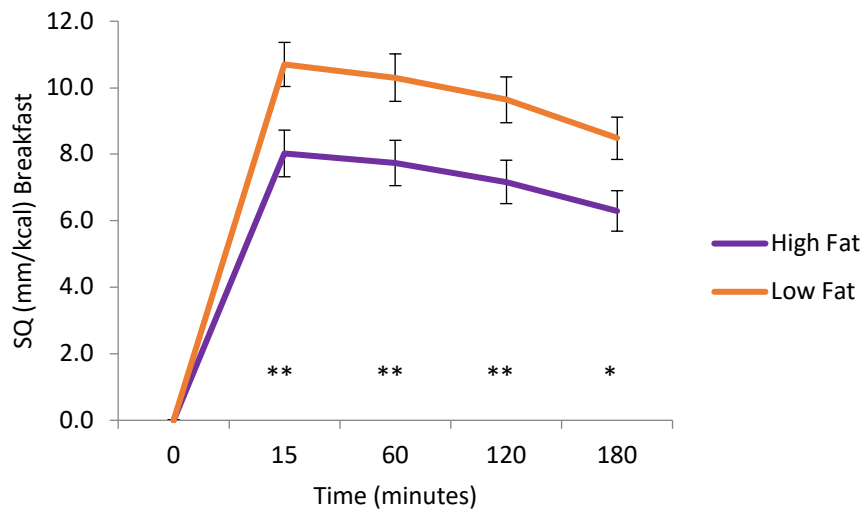
Figure 5.4. Satiety Quotient for the 180 minute period post consumption of the high fat and low fat ad libitum breakfast test meals. Note: *$p < 0.05$; **$p < 0.01$.
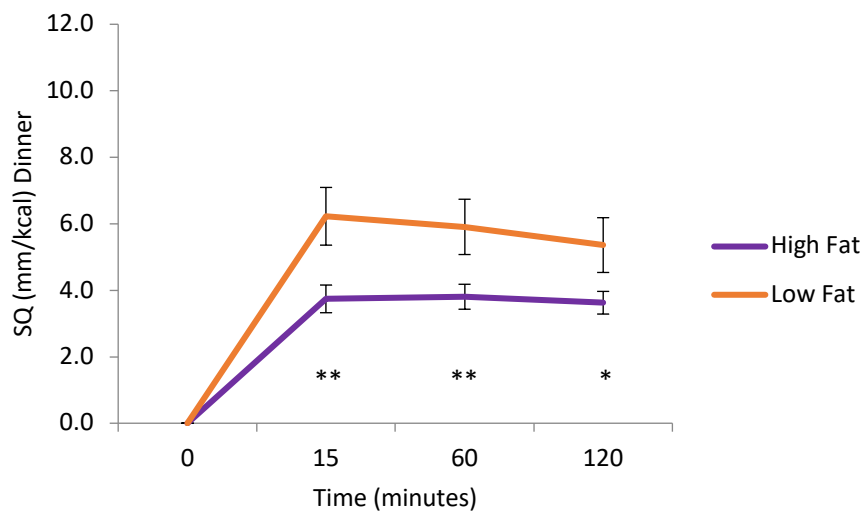
Figure 5.5. Satiety Quotient for the 120 minute period post consumption of the high fat and low fat ad libitum dinner test meals. Note: *$p < 0.05$; **$p < 0.01$.
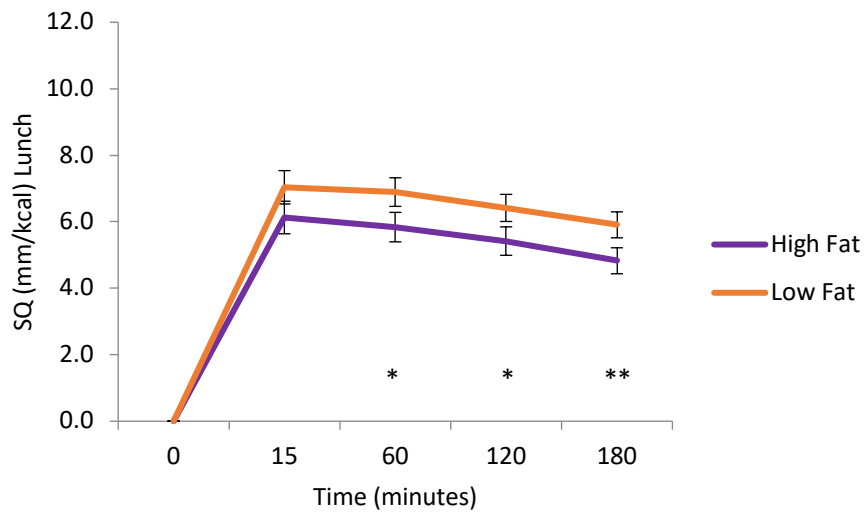
Figure 5.6. Satiety Quotient for the 180 minute period post consumption of the high fat and low fat fixed energy lunch test meals. Note: *p<0.05; **p<0.01.

5.4.5   Reliability of the Satiety Quotient

There was a significant correlation between SQ for the high fat and low fast test meals at lunch [r = 0.51, p<0.01] and dinner [r = 0.42, p<0.01].
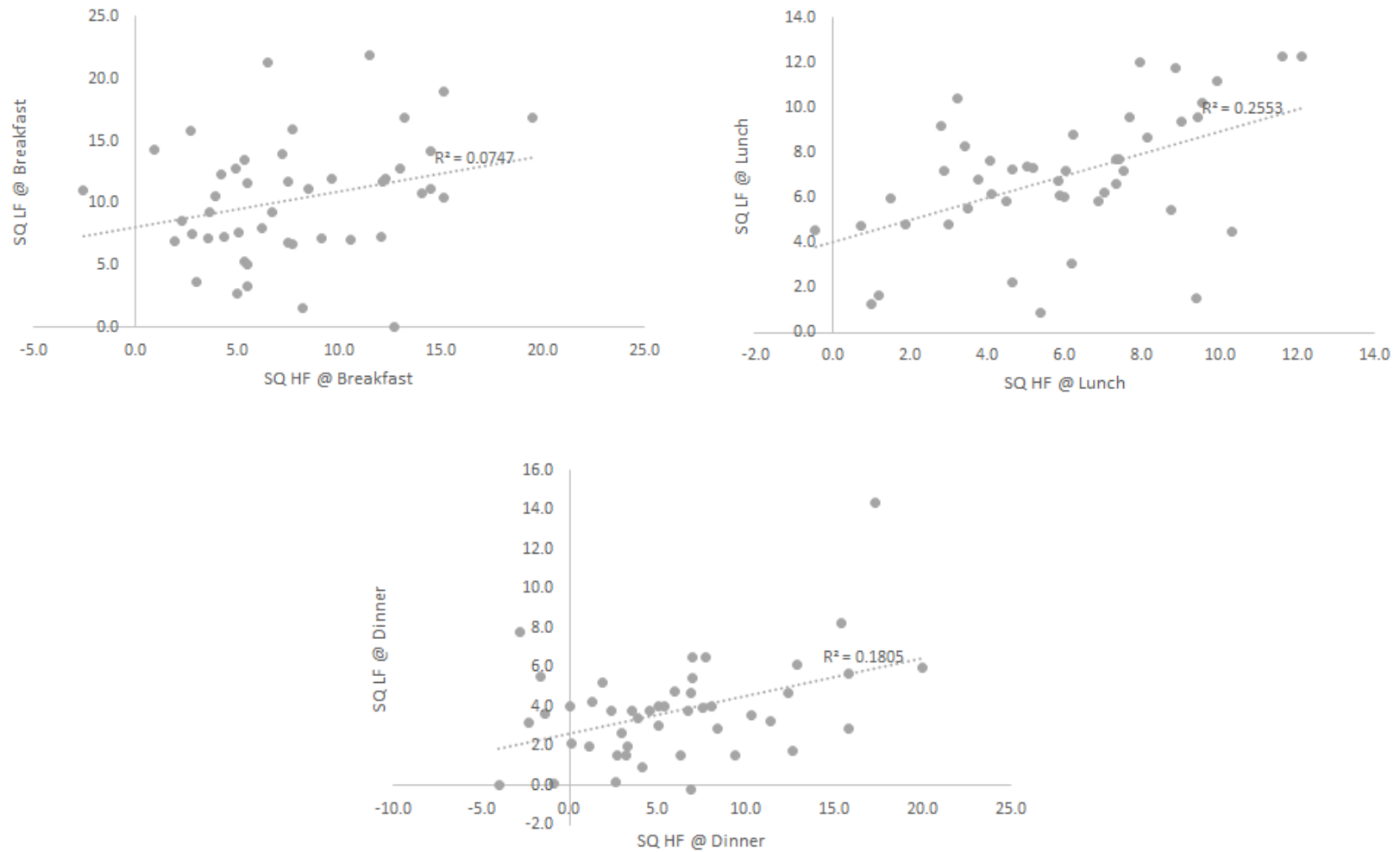
Figure 5.7. Correlation between SQ for the high fat and low fat test meals at (a) breakfast (b) lunch and (c) dinner.

5.5   Discussion

The aim of the present study was to examine the effects of macronutrient manipulation (high fat vs. low fat test meals) on satiety and energy intake. In addition, the present study also aimed to determine the extent to which the satiety quotient was a consistent measure of satiety responsiveness across the high fat and low fat test conditions. The current study found that consumption of low fat foods resulted in greater satiation (lower energy intake at ad libitum test meals), greater postprandial satiety (higher SQ values) and lower total daily energy intake compared with the consumption of high fat foods. Furthermore, there was a significant correlation between the SQ for the high fat and low fat test meals at lunch and dinner. These findings suggest that foods that are low in fat/high in carbohydrate produce better short term appetite control than foods that are high in fat/low in carbohydrate. In addition, the present findings provide additional support for the use of the SQ as a measure of individual satiety responsiveness, demonstrating that the SQ is able to detect differences in macronutrient manipulations in line with previous research (Stubbs et al., 2000), while remaining consistent across the macronutrient conditions.

The present study demonstrated a clear effect of macronutrient composition on satiation and total energy intake. Total energy intake was greater on the high fat compared to the low fat test day. Participants consumed more energy from both the high fat breakfast and the high fat dinner test meals compared to the equivalent low fat test meals. In line with previous findings (Blundell et al., 1996). There was also a clear effect of macronutrient composition on satiety, when measured using the satiety quotient. The low fat/high carbohydrate breakfast and dinner test meals which were served to participants ad libitum, were found to be more satiating than the equivalent high fat/low carbohydrate meals, producing higher postprandial SQ scores. These differences were evident despite the lower energy content of the low fat/high test meals, and no differences between ratings of hunger before eating. The effect of macronutrient composition was also evident following the fixed energy test meal. In addition, the low fat/high carbohydrate lunch was found to be more satiating than the equivalent high fat/low carbohydrate equivalent, albeit to a lesser extent, producing greater SQ scores. These findings, that low fat/high carbohydrate foods reduce energy intake as well as increase postprandial satiety are in line with previous findings (Blundell et al., 1993; Lawton et al., 1993) and contribute towards the emerging support for the use of the SQ as a measure of satiety responsiveness. Here we have demonstrated that SQ is not only sensitive to the energy

and macronutrient content of foods but remains so even when energy content is controlled. Existing research provides some support and possible explanations for the findings of the current study. For instance, alterations in physiological signals as a result of the fat and carbohydrate content of the meals may underlie the differences in satiation and satiety in the present study (Gibbons et al., 2013; Essah et al., 2007; Bowen et al., 2006). A more recent study (Hopkins et al., 2016) suggests that high fat/low carbohydrate foods promote an increase in subsequent energy intake through an effect on hedonic appetite as well as on satiation and satiety. It should also be noted that high fat and low fat foods often differ in weight and volume (even if isoenergetic) and these two features both contribute to the subjective experiences generated by food consumption.

In the present study there was a significant correlation between SQ for the high fat and low fat test meals. This finding demonstrates that the SQ is able to detect differences in macronutrient manipulations, in line with that of previous research on satiety, while remaining consistent at an individual level across macronutrient conditions. Thus, providing support for the use of the SQ as a measure of satiety responsiveness.

The findings of the current study are consistent with those of previous work which goes someway to increase confidence in their reliability. Furthermore, the current study assessed the reliability of the SQ, in response to a macronutrient manipulation, in a sample of overweight and obese individuals. Therefore, providing additional support to the findings of the previous study (Chapter 4) which established that the SQ is a reliable measure of satiety responsiveness in normal weight individuals. Future research could extend the findings of the current study by exploring further the response of the low satiety phenotype to macronutrient manipulations such as this. It would be interesting, for example, to determine whether the low satiety phenotype exhibit a weakened satiety response to all foods. Or whether certain foods, for example those foods designed to have a high satiating impact, specifically alter the satiety responsiveness of the low satiety phenotype. In addition, manipulating the whole diet rather than single test meals over a longer period of time, would provide further support for the clinical importance of satiety responsiveness and may present an effective nutritional strategy. The impact of a satiating diet has been assessed in the low satiety phenotype (Arguin et al., 2017).

To conclude, the present study found that high fat/low carbohydrate foods have a weaker influence on satiety and promote greater energy intake compared to low fat/high carbohydrate foods. Specifically, the satiety quotient, as a measure of satiety responsiveness, is sensitive to different macronutrient manipulations. Furthermore,

despite the variability in the satiety quotient in response to the different macronutrients, intraindividual variability is low. These findings provide additional support for the use of the satiety quotient, as a reliable and consistent measure of satiety responsiveness.

Chapter 6

Examination of Behavioural and Psychological Risk Factors for Overeating in the Low Satiety Phenotype

6.1 Abstract

Background: The current thesis has demonstrated that some individuals exhibit a weak satiety response to food and as a result may be susceptible to overconsumption. The present study identified women who reliably demonstrated low or high satiety responses to standardised servings of food across separate days and characterised these phenotypes in relation to physiological, behavioural and psychological risk factors for overeating.

Methods: In a randomised, counterbalanced, within subjects design, thirty female participants (age: 28.0±10.6, BMI: 23.1±3.0) recorded subjective appetite sensations during the postprandial period following four breakfasts that were individually calibrated to provide increasing levels of measured resting energy requirements. Body composition was measured using air plethysmography and resting metabolic rate was measured via indirect calorimetry. Ad libitum energy intake was assessed at lunch. The Three Factor Eating Questionnaire, Binge Eating Scale and Control of Eating Questionnaire were used to assess eating behaviour and craving for food. Food reward was measured using the Leeds Food Preference Questionnaire. Satiety responsiveness and the low satiety phenotype were determined using the satiety quotient.

Results: A distinct low satiety phenotype was consistently and reliably identified across the four study conditions. The low satiety phenotype had greater levels of disinhibition and exhibited a greater wanting for high fat foods. Furthermore, they consumed more energy at the ad libitum lunch, confirming that the low satiety phenotype defined by the satiety quotient did indeed reveal a tendency to subsequently eat more food.

Conclusion: The low satiety phenotype are characterised by distinct behavioural and psychological characteristics that may increase their susceptibility to overeating, compared to the high satiety phenotype.

6.2   Introduction

For some individuals, certain characteristics of the expression of appetite may result in increased vulnerability to overconsume. For instance, a weakened satiety response to food has been proposed as a possible marker of susceptibility to overeating (Schachter, 1968; Blundell & Gillett, 2000; Barkeling et al., 2007, Drapeau et al., 2011). Based on experimental observations such as these it is clear that some individuals express a weaker satiety response following a caloric load and it is reasonable to propose that in these individuals impaired satiety signals could promote overconsumption and increase the risk of weight gain.

Satiety responsiveness can be objectively measured using the satiety quotient, which represents a change in recorded appetite sensations, in response to a standardised meal, per unit of intake (Green et al., 1997). There is support for the use of appetite sensations and the satiety quotient as methods of measuring satiety responsiveness (Arvaniti et al., 2000; Stubbs et al., 2000; Drapeau et al., 2005; Drapeau et al., 2007). The satiety quotient can be used to classify individuals according to their individual satiety efficiency; whereby a higher SQ represents a stronger appetite response or greater satiety signalling capacity, while a lower SQ represents a weaker appetite response or poorer satiety signalling capacity.

Using the satiety quotient and a test meal Drapeau and colleagues demonstrated SQ for fullness to be negatively associated with both total energy intake and relative energy intake in normal weight, obese and reduced-obese individuals (Drapeau et al., 2005). Therefore, were able to conclude that individuals with low SQ, who experienced almost no change in meal induced fullness, had higher energy intakes. These findings were confirmed in a subsequent study (Drapeau et al., 2007) conducted on a larger more homogenous sample of obese men and women. Here the negative relationship between SQ for fullness and total energy intake proved stronger for women. Together these findings indicate that individuals characterised as having a low SQ have weaker appetite sensation responses following a meal and as a result could be more vulnerable to overconsumption.

More recently a low satiety phenotype has been identified (Drapeau et al., 2013). Drapeau and colleagues (2013) used the satiety quotient to identify a low satiety phenotype which demonstrate an impaired capacity to detect appetite sensations and experience reduced intensity and duration of post-ingestive activity. Furthermore, the

low satiety phenotype were associated with greater anxiety, higher levels of disinhibition and external locus of hunger as well as a blunted cortisol response to food.

In the first study, presented in Chapter 4, correlation coefficients for SQ for all appetite sensations, across the study visits, which were conducted a week apart, ranged between $r = 0.49 – 0.64$ (Study 1a) and $r = 0.59 – 0.70$ (Study 1b). These correlations across the measures of SQ which were conducted a week apart, represents a moderate agreement which demonstrates good reproducibility. In addition, the satiety quotient was associated with a number of risk factors for overconsumption including greater TFEQ Hunger, ad libitum energy intake (Study 1a) and resting metabolic rate (Study 1b). As well as lower baseline hunger ratings (both Study 1a and Study 1b). These associations suggest that low satiety responsiveness may be associated with risk for overconsumption. Replication of these associations is required to provide further support for the use of the SQ as a measure of satiety responsiveness and to determine whether the low satiety phenotype is a distinct phenotype characterised by behavioural and psychological factors.

6.2.1   Study Aims

The first aim of the current study was to confirm the validity of the Satiety Quotient to categorise individuals as low or high in satiety responsiveness. In addition, the present study aimed to characterise the behavioural and psychological risk profile for overeating and obesity in the low satiety phenotype. This study will serve to test further the validity of the satiety quotient as a measure of satiety responsiveness, as well as confirm whether the low satiety phenotype is a distinct phenotype characterised by behavioural and psychological factors associated with risk of overeating.

6.3   Method

6.3.1   Participants

Participants were recruited via a University of Leeds email distribution list, which staff and students as well as members of the public are able to sign up to. The recruitment email included information about the study, the inclusion criteria and a screening questionnaire which was used to determine eligibility. The inclusion criteria for the study was healthy female participants, aged 18-55 years, with a BMI between 18.5-30.0 kg/m². Participants who were taking medication known to affect appetite, currently dieting to lose or maintain weight, not regular breakfast consumers, smokers, reported a history of eating disorders or were unfamiliar with or disliked any of the study foods were excluded.

Participants were invited to attend a screening session at the Human Appetite Research Unit, to confirm their eligibility and have the research procedure presented to them. Thirty female participants (age: 28.0±10.6, BMI: 23.1±3.0) were recruited to the study. All participants provided written informed consent and study procedures were reviewed and approved by the University of Leeds, School of Psychology Ethics committee.

6.3.2 Design

The present study followed a randomised, counterbalanced, within subjects design. Each participant attended the Human Appetite Research Unit at the University of Leeds on five occasions; this included a screening and measures session, followed by four experimental sessions. Each study session was scheduled at least seven days apart. For all sessions participants arrived at the research unit following an overnight night fast. Participants were instructed not to consume alcohol or engage in physical activity for 24-hours and not to consume caffeine for 12-hours prior to the sessions. Compliance with this instruction was assessed at the beginning of each session by self-report. During the experimental sessions participants consumed both the breakfast and lunch test meals at the research unit. They were permitted to leave the unit in the period between breakfast and lunch but were instructed not to eat or drink anything besides water. Ratings of subjective appetite were taken at regular intervals throughout the test day using a validated hand-held Electronic Appetite Rating System (EARS-II; Gibbons et al., 2010). The breakfasts provided to participants were fixed and individually calibrated (proportional to either 20%, 25%, 30% and 35% of participants individual energy requirements). This enabled the mean SQ to be calculated and satiety responsiveness to be determined for each participant. An ad libitum lunch test meal was used to assess energy intake. Craving for food was assessed using the Control of Eating Questionnaire and food reward was measured using the Leeds Food Preference Questionnaire.

6.3.3 Measures

6.3.3.1 Resting Metabolic Rate

Participants resting metabolic rate was measured during the measures session, using an indirect calorimeter fitted with a ventilated hood (GEM; Nutren Technology Ltd). Resting metabolic rate was used to calibrate the standard fixed energy breakfast served to participants. This measure is described in more detail in Chapter 3.

6.3.3.2   Anthropometrics and Body Composition

Height was measured to the nearest 0.5cm using a stadiometer, body weight was measured to the nearest 0.1kg using an electronic balance and waist circumference was measures at the participants naval after expiration. Body composition (fat mass, fat free mass and percentage body fat) was assessed using air plethysmography (BodPod, Concord, CA, USA). All anthropometric and body composition measures were conducted during the measures session and are described in more detail in Chapter 3.

6.3.3.3   Eating Behaviour Questionnaires

Participants completed numerous eating behaviour questionnaires during the measures session including the Three Factor Eating Questionnaire (TFEQ; Stunkard & Messick, 1985); Control of Eating Questionnaire (CoEQ; Hill et al., 1991; Dalton et al., 2017) and Binge Eating Scale (BES; Gormally et al., 1982). These questionnaires were used to assess levels of restraint, disinhibition and hunger; mood, appetite and experience of food craving, as well as binge eating severity and are described in more detail in Chapter 3.

6.3.3.4   Subjective Appetite Sensations

Subjective ratings of appetite (hunger, fullness, desire to eat and prospective consumption) were measured using 100-mm VAS presented on an Electronic Appetite Rating System (EARS). Ratings were completed at baseline, then every thirty minutes throughout the morning as well as before and after each event in the procedure. These measures of subjective appetite are described in more detail in Chapter 3.

6.3.3.5   Energy Intake

6.3.3.5.1   Fixed Energy Breakfast

The fixed energy breakfasts served to participants comprised of muesli (muesli base, raisins, sultanas) combined with natural yoghurt, semi-skimmed milk and honey, see Table 1 for details. The breakfasts were individually calibrated to provided 20%, 25%, 30% and 35% of participants individual energy requirements (see Table 2 for average energy provided in each condition). The amount of water served alongside the breakfast was adjusted so that the total weight of the breakfast and the water consumed was kept constant. Participants had the choice of either tea, coffee or water. Both tea and coffee was served without sugar and milk if required came out of the breakfast allowance. Participants were given 15 minutes to consume breakfast in its entirety.

Table 6.1. Nutritional information for the fixed energy breakfast items.

Breakfast Item	KCAL/100g	CHO/100g	FAT/100g	PRO/100g
Neal's Yard Muesli Base	360.0	70.0	5.0	13.0
Neal's Yard Raisins	268.6	69.3	0.0	2.1
Neal's Yard Sultanas	274.7	69.4	0.4	2.7
Yeo Valley Natural Yoghurt	82.0	6.5	4.2	4.6
Sainsbury's Runny Honey	319.5	84.3	0.2	0.4
Semi-skimmed Milk	50.0	4.8	1.1	3.6

Table 6.2. Mean (standard deviation) energy provided at breakfast for the 20%, 25%, 30% 35% energy requirement conditions.

Condition	Mean (SD)	Range
20%	258.8 (29.9)	209.8 – 328.6
25%	318.3 (34.5)	265.0 – 402.2
30%	392.6 (40.8)	334.0 – 494.2
35%	467.0 (47.6)	403.0 – 586.2

6.3.3.5.2 Ad Libitum Energy Intake

Energy intake was assessed using an ad libitum lunch test meal which consisted of tomato and herb risotto, garlic bread and strawberry yoghurt, see table 3 for details. Lunch was served 4 hours following the breakfast and participants were instructed to consume as much or as little as they wanted, but to eat until comfortably full. Food was weighed pre- and post- consumption to the nearest 0.1g to determine energy intake.

Table 6.3. Serving size (g) and nutritional information for the lunch food items.

Lunch Item	Serving (g)	KCAL/ 100g	CHO/ 100g	FAT/ 100g	PRO/ 100g
Uncle Bens Tomato & Herb Risotto	900	178	31.4	3.9	3.7
Sainsbury's Olive Oil	45	823	0.5	91.5	0.5
Yeo Valley Strawberry Yoghurt	425	106	13.2	3.8	4.7
Sainsbury's Double Cream	45	439	1.5	47.5	1.5
Sainsbury's Garlic Bread	200	362	36.9	20.7	5.6

Note: The olive oil was mixed in with the risotto and the cream with the yoghurt.

6.3.3.6   Leeds Food Preference Questionnaire

The Leeds Food Preference Questionnaire (LFPQ) was used to assess both explicit liking and implicit wanting. Participants completed the LFPQ immediately prior to the lunch test meal, in a fasted state. The LFPQ is described in more detail in Chapter 3.

6.3.3.7   Satiety Quotient

Hunger VAS ratings were used to calculate satiety quotient (SQ) for the 75-minute period post breakfast. SQ was then used to categorise participants as high or low in satiety responsiveness. Both methods are described in more detail in Chapter 3.

The following formula was used to calculate SQ:

$$SQ \text{ (mm/kcal)} = \left(\frac{\text{rating before eating} - \text{mean of the 75-min post meal ratings}}{\text{energy content of the test meal (kcal)}} \right) \times 100$$

6.3.4   Procedure

Participants attended the research unit on five occasions: a screening and measures session, followed by four experimental sessions. For the screening and measures session participants arrived at the research unit between 7.00am-9.00am, eligibility was confirmed and participants provided written informed consent. Height, weight, waist circumference, resting metabolic rate and body composition were then measured. Participants also completed a set of eating behaviour questionnaires (TFEQ, CoEQ, BES). For the experimental sessions participants arrived at the research unit between 8.00am-9.00am. On arrival participants were shown to a research cubicle where they completed the first set of VAS ratings and consumed breakfast. Following breakfast a second set of VAS ratings were completed and participants were free to leave the research unit but were asked to return 4 hours later for lunch. During this time the EARS-II prompted completion of the VAS ratings at 30-minute intervals. During the lunchtime session, participants completed the LFPQ, once before and then again after the ad libitum lunch test meal. Participants completed VAS ratings before and after each event in the lunchtime procedure. The following experimental sessions were identical apart from the breakfast served to participants. On completion of all five sessions participants received a debrief and were compensated £30 for taking part in the study. See below for a schedule of the VAS ratings taken across the study test day (Table 4) as well as a schematic representation of the experimental session (Figure 1).

Table 6.4. Schedule of VAS ratings taken across the day - experimental session.

Rating	Event	Time
1	Baseline	-5minutes
2	Post-Breakfast	+15minutes
3	Completed away from HARU	+30minutes
4	Completed away from HARU	+60minutes
5	Completed away from HARU	+90minutes
6	Completed away from HARU	+120 minutes
7	Completed away from HARU	+150 minutes
8	Completed away from HARU	+180minutes
9	Completed away from HARU	+210 minutes
10	Pre-LFPQ	+230minutes
11	Post-LFPQ/Pre-Lunch	+240minutes
12	Post-Lunch	+270minutes
13	Final VAS Rating	+280minutes
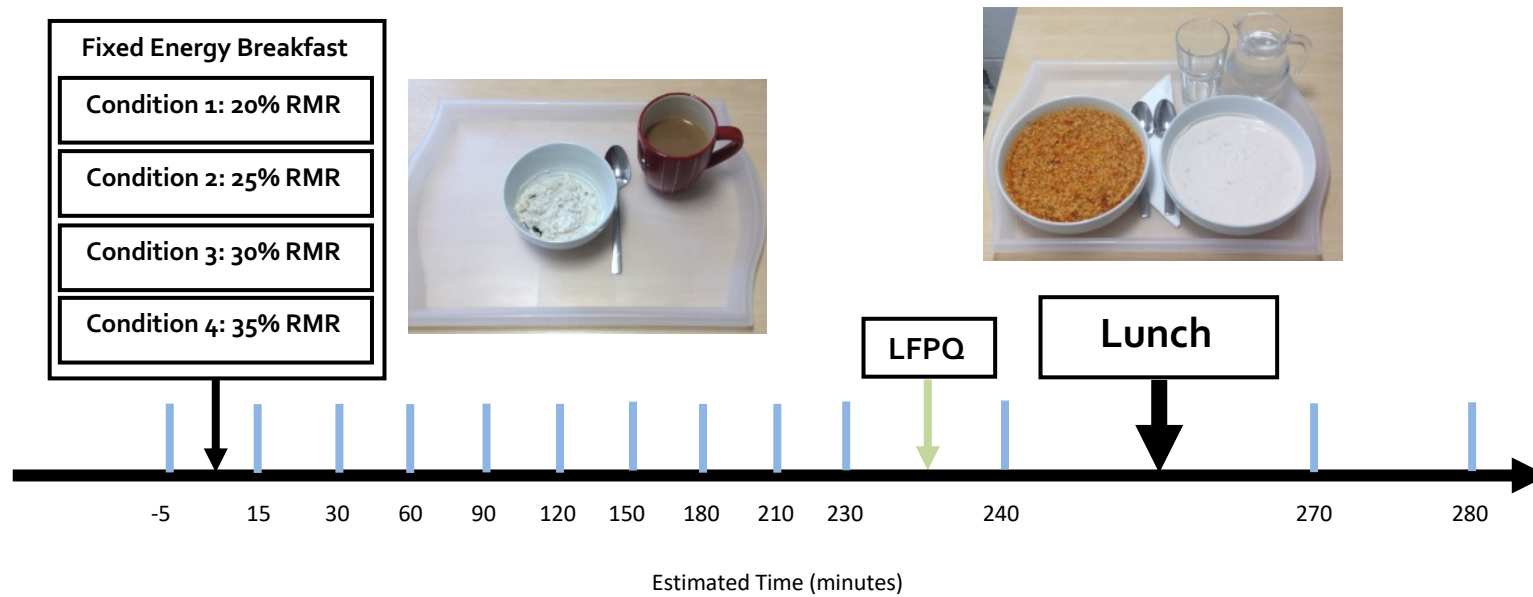
Figure 6.1. Schematic representation of experimental session.

Blue vertical bars indicate where visual analogue scale appetite sensations were measured.

6.3.5 Data Analysis

Data was analysed using statistical Programme for Social Sciences Version 22. Pearson correlation coefficients were used to assess the relationship between physiological, psychological and behavioural variables and the SQ. Pearson correlation coefficients were also used to assess the reliability of the satiety quotient across experimental sessions. Participants were then characterised according to individual satiety efficiency using average SQ for the 75-minute period following breakfast and a tertile split to identify high and low cut off points. Independent t-tests were used to compare scores on a numerous baseline measures (physiological, psychological and behavioural) for the high and low satiety phenotype. The effect of satiety responsiveness on appetite sensations was assessed using 2x13 repeated measures ANOVAs. Finally, independent t-tests were also used to examine the effect of satiety responsiveness on energy intake and food reward (liking and wanting fat appeal biases and food craving). Where appropriate Greenhouse-Geisser probability levels were used to adjust for non-sphericity. Where significant effects were obtained post hoc analyses, with a Bonferroni correction for multiple comparisons were conducted. An α-level of .05 was used to determine significance and Cohen's d was used as a measure of effect size.

6.4 Results

6.4.1 Participant Characteristics

Table 6.5. Mean (standard deviation) and range for age, anthropometrics, body composition, TFEQ restraint, disinhibition, hunger and binge eating score.

	Mean (SD)	Range
Age	28.0 (10.6)	20.0 – 54.0
Weight (kg)	62.7 (9.1)	46.3 – 84.7
BMI (kg/m^2)	23.1 (2.9)	18.1 – 29.1
Waist (cm)	77.2 (8.1)	66.0 – 102.0
Fat mass (kg)	19.6 (5.5)	10.8 – 32.3
Fat free mass (kg)	43.1 (5.2)	34.0 – 55.0
Body fat (%)	30.9 (5.2)	22.6 – 41.8
TFEQ Restraint	9.9 (5.4)	3.0 – 20.0
TFEQ Disinhibition	7.2 (3.2)	0.0 – 12.0

TFEQ Hunger	6.5 (3.4)	0.0 – 12.0
Binge Eating Score	12.9 (6.8)	0.0 – 25.0

6.4.2 Validity of the Satiety Quotient as a Marker of Susceptibility

The average SQ across all study conditions was negatively associated with resting metabolic rate (r (30) = -.456, p<0.05), a greater implicit wanting fat bias (r (29) = -.459, p<0.05) and TFEQ disinhibition (r (29) = -.464, p<0.05). These associations suggest that a low SQ is associated with risk factors for overconsumption. To explore these associations further we categorised individuals according to satiety efficiency.

6.4.3 Categorisation and Characterisation of Satiety Phenotypes

To categorise participants according to individual satiety efficiency, satiety quotient for the 75-minute period following each breakfast was calculated and an average across the four visits was determined. A tertile split was used to calculate high and low cut-off points. The low satiety phenotype were identified as those who had a SQ ≤8.1 whereas the high satiety phenotype were identified as those who had a SQ ≥13.6. Ten participants were not categorised as either high or low satiety responders and were not included in any subsequent analyses. Table 5 shows the participant characteristics for the low and the high satiety phenotype. As expected the low satiety phenotype had a significantly lower SQ across the study visits compared to the high satiety phenotype (t (14) = 8.89, p<0.001, *d* = 3.9). In addition, the low satiety phenotype reported lower baseline hunger (t (18) = 5.54, p<0.001, *d* = 2.5), desire to eat (t (18) = 4.32, p<0.001, *d* = 1.9) and prospective consumption (t (18) = 3.83, p<0.01, *d* = 1.7), as well as greater baseline fullness (t (18) = 2.75, p<0.05, *d* = 1.2) compared to the high satiety phenotype. Furthermore, the low satiety phenotype had greater TFEQ disinhibition scores (t (17) = 2.62, p<0.05, *d* = 1.2) compared to the high satiety phenotype.

Table 6.6. Mean (standard deviation) age, appetite sensations, anthropometrics, body composition and eating behaviour traits for the low and high satiety phenotypes.

	Low Satiety Phenotype (n, 10)	High Satiety Phenotype (n, 10)	Uncategorised (n,10)
SQ (mm/kcal)[1]	6.01 (1.9)***	17.7 (3.7)***	10.6
Hunger (mm)[1]	46.2 (14.3)***	78.2 (11.4)***	60.7
Desire to Eat (mm)[1]	47.6 (16.4)***	75.9 (12.7)***	59.7

Prospective Consumption (mm)[1]	41.3 (12.6)**	63.2 (12.9)**	52.0
Fullness (mm)[1]	32.7 (10.7)*	18.1 (12.9)*	19.9
Age (years)	25.8 (8.9)	31.3 (14.7)	26.9
Weight (kg)	65.5 (12.2)	60.5 (6.5)	62.1
BMI (kg/m^2)	23.6 (3.4)	22.9 (2.7)	22.9
Waist (cm)	79.2 (10.4)	74.3 (6.7)	77.9
Fat mass (kg)	20.6 (6.1)	18.7 (5.2)	19.5
Fat free mass (kg)	44.9 (7.1)	41.8 (3.9)	42.6
Body fat (%)	30.9 (4.7)	30.6 (5.9)	31.0
Resting Metabolic Rate (kcal)	1361.8 (206.8)	1225.8 (114.9)	1288.7
TFEQ Restraint	9.2 (5.4)	10.3 (6.1)	10.0
TFEQ Disinhibition	9.0 (2.0)*	5.3 (3.8)*	7.6
TFEQ Hunger	7.7 (2.7)	5.8 (3.9)	6.1
Binge Eating Score	15.3 (6.0)†	9.4 (6.8)†	14.0

Note: [1]Average collapsed across conditions; *$p<0.05$; **$p<0.01$; ***$p<0.001$; †$p = .05$. Hunger, Fullness, Desire to Eat and Prospective Consumption are all baseline.

6.4.4   Subjective Appetite Sensations
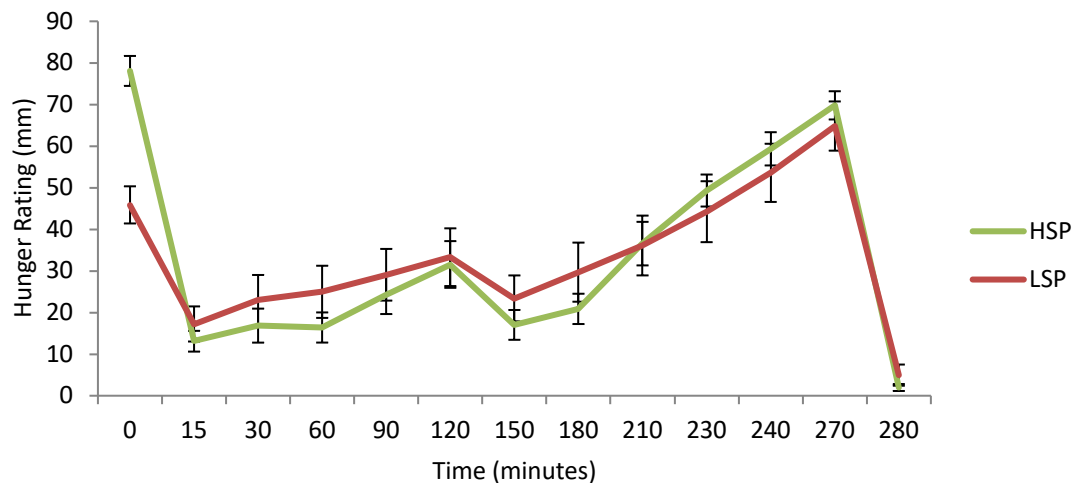
Figure 6.2. Ratings of hunger for the high and low satiety phenotype across the test day. Note: Ratings collapsed across study visits; ***$p<0.001$.

There was a main effect of time on ratings of hunger, desire to eat, prospective consumption and fullness ($F_{(5,89)} = 93.4$, $p<0.001$; $F_{(4,68)} = 73.8$, $p<0.001$; $F_{(5, 81)}$

= 88.0, p<0.001; F (5,83) = 54.1, p<0.001, respectively). In addition, there was an interaction between time and satiety phenotype for hunger (F (5,89) = 7.12, p<0.001), desire to eat (F (4,68) = 3.99, p<0.05), prospective consumption (F (5,81) = 4.97, p<0.01) and fullness ratings (F (5, 83 = 2.78, p<0.05). Post hoc analyses revealed that the low satiety phenotype had significantly lower baseline hunger, desire to eat and prospective consumption and greater fullness compared to the high satiety phenotype.

6.4.5   Ad Libitum Energy Intake

Figure 3 shows ad libitum energy intake from the lunch test meal for the low and the high satiety phenotype. Overall, the low satiety phenotype consumed more energy from the ad libitum lunch test meal (t (18) = 2.39, p<0.05, d = 1.1) compared to the high satiety phenotype. Further analyses revealed that the low satiety phenotype consumed more energy from both the risotto (t (18) = 2.21, p<0.05, d = 0.9) and the garlic bread (t (18) = 2.28, p<0.05, d = 1.0) components compared to the high satiety phenotype.
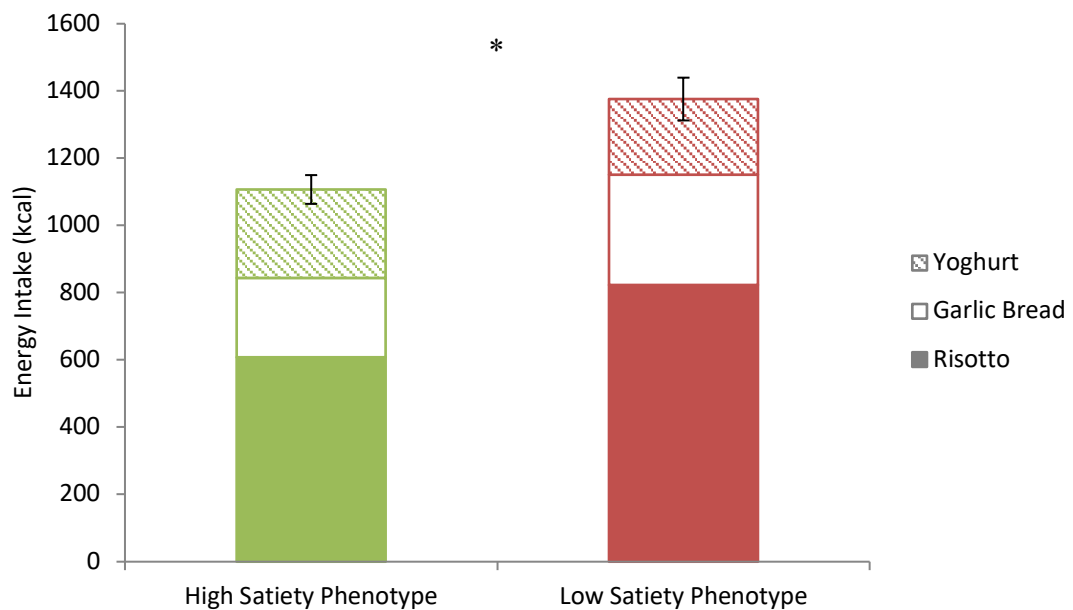
Figure 6.3. Energy intake (kcal) from the ad libitum lunch test meal for the low and the high satiety phenotype. Note: Energy intake collapsed across conditions; *p<0.05.

6.4.6   Food Hedonics

6.4.6.1   Explicit Liking and Implicit Wanting Fat Appeal Bias

Figure 4 and Figure 5 show explicit liking and implicit wanting fat appeal bias, respectively, for the low and the high satiety phenotype. Analysis of the explicit liking fat appeal bias revealed that the low satiety phenotype had a greater liking for high fat

foods when hungry compared to the high satiety phenotype who demonstrated a greater bias for low fat foods when fasted. However, the mean difference between groups did not reach statistical significance (t (18) = 1.95, p = .07). Furthermore, analysis of the implicit wanting fat appeal bias demonstrated that the low satiety phenotype had a greater bias for high-fat foods when hungry compared to the high satiety phenotype who demonstrated a greater bias for low-fat foods (t (18) = 2.87, p<0.05, d = 1.3) when fasted.
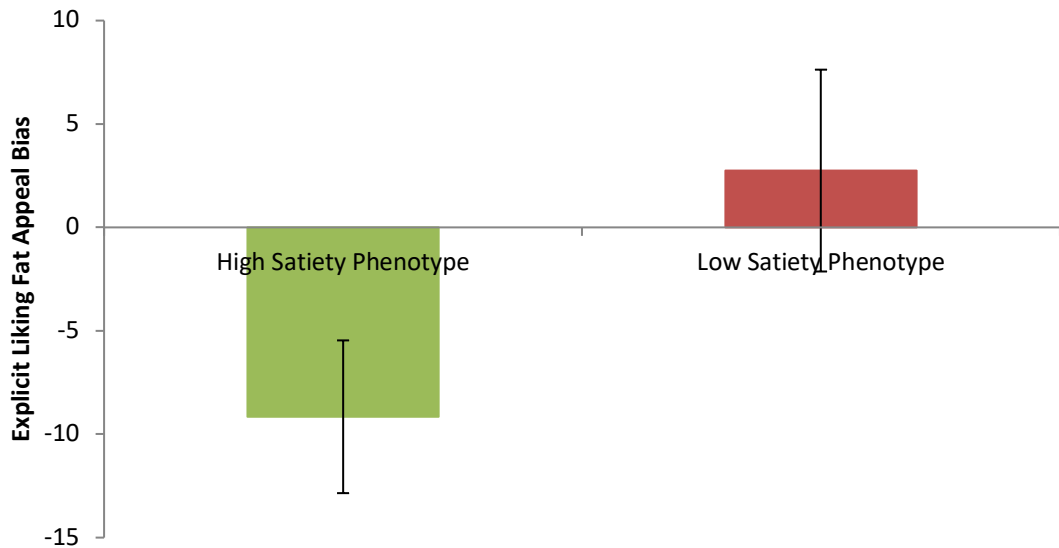
Figure 6.4. Explicit liking fat appeal bias for the low and the high satiety phenotype. Note: A positive value indicates a bias towards high fat foods.
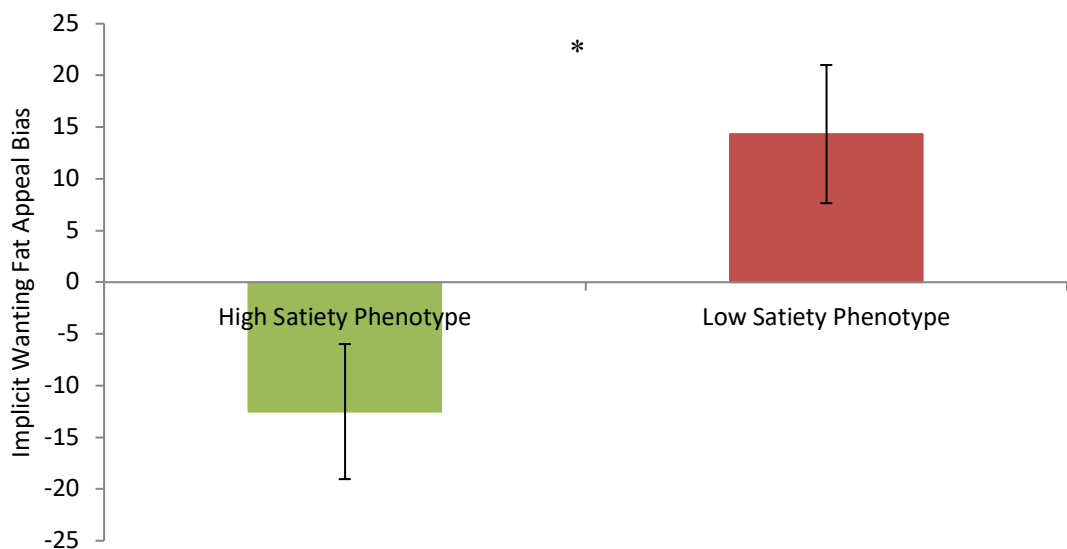
Figure 6.5. Implicit wanting fat appeal bias for the low and the high satiety phenotype. Note: A positive value indicates a bias towards high-fat foods; *p<0.05.

6.4.6.2   Craving for Food

Analysis of craving for food revealed no differences between the high and the low satiety phenotype on Craving Control, Craving for Sweet, Craving for Savoury and Positive Mood subscales of the CoEQ (t (18) = 0.53, p = .60; t (18) = -0.25, p = .80; t (18) = -1.15, p = .27; t (18) = 0.52, p = .61, respectively).

6.5   Discussion

The first aim of the current study was to confirm the reliability and validity of the Satiety Quotient as a measure of satiety responsiveness and a means of identifying individuals who exhibit a weak satiety response to food. The second aim of the study was to characterise the behavioural, psychological and physiological risk profile for overeating in those individuals identified as being low or high in satiety responsiveness.

The current study found that low SQ was associated with higher resting metabolic rate, a greater implicit wanting for high fat foods and higher scores on the TFEQ Disinhibition subscale. These associations suggest that a low SQ is associated with risk factors for overconsumption. To explore these associations further we categorised individuals according to their satiety phenotype. A distinct low satiety phenotype was reliably identified across study conditions. The low satiety phenotype had greater levels of disinhibition and exhibited a greater wanting for high fat foods compared to the high satiety phenotype. Furthermore, they consumed more energy at the ad libitum lunch.

Specifically we found that the low satiety phenotype had greater TFEQ Disinhibition scores compared to the high satiety phenotype. Disinhibition can be described as the tendency to eat opportunistically (Bryant, King & Blundell, 2008) and greater levels of disinhibition have been consistently associated with increased ad libitum energy intake (Chambers & Yeomans 2011; Ouwens et al., 2003) and increased tendency for weight gain (Carr et al., 2013; Finlayson et al., 2012) in previous studies. In addition to this, several studies have demonstrated that disinhibition is associated with weak satiety responsiveness (Finlayson et al., 2012; Cornier et al., 2004) which is consistent with our current findings. For example, Finlayson et al (2012) found that greater levels of disinhibition were associated with lower satiating efficiency of sweet/savoury preloads. We have previously found (Study 1a) that low SQ was associated with higher scores on the TFEQ Hunger subscale. Here the low satiety phenotype had greater TFEQ Hunger scores compared to the high satiety phenotype. Taken together these findings suggest

that the low satiety phenotype who have been shown exhibit weak satiating efficiency, also display psychological traits that would increase their susceptibility to overeating.

In addition, to measure hedonic risk factors for overconsumption in the low satiety phenotype, we assessed liking and wanting appeal bias for high fat versus low fat foods. We found that the low satiety phenotype consistently exhibited a greater wanting appeal bias for high fat foods compared to the high satiety phenotype. This means that they chose high fat foods more frequently and faster than they chose low fat foods. Previous research has shown that increased wanting for high food is associated with greater compensatory eating behaviours following physical activity, greater binge eating tendencies and greater overall energy intake (Finlayson et al., 2011; Dalton, Finlayson & Blundell 2013; Saelens & Epstein 1996; Finlayson, Bryant & Blundell 2009). In contrast, the high satiety phenotype consistently exhibited a greater wanting appeal bias for low fat foods compared to the low satiety phenotype. This preference may be protective against overeating and creating a positive energy balance. Certainly research has demonstrated that greater preference for low fat foods is negatively associated with energy intake both under laboratory and using 24hr dietary recall under free living conditions (Dalton, 2013). These finding are the first to suggests that the low satiety phenotype may be characterised by hedonic risk factors for overconsumption.

Furthermore, we demonstrated that the low satiety phenotype consumed significantly more energy at the ad libitum lunch test meal compared to the high satiety phenotype. This finding is consistent with previous research that has shown a low SQ in response to a standardised test meal is negatively associated with energy intake under laboratory and free living conditions (Drapeau et al., 2005; Drapeau et al., 2007). Despite the low satiety phenotype consuming more energy at the ad libitum lunch test meal, we did not find that the low satiety phenotype consistently reported greater levels of hunger, fullness, prospective consumption or lower levels of fullness across the test day. Based on these energy intake findings, it may have been expected that the low satiety phenotype would have higher levels of baseline hunger, desire to eat and prospective consumption. However, we found that the low satiety phenotype reported lower levels of baseline hunger, prospective consumption and desire to eat and greater levels of baseline fullness. One explanation for this may be that following a period of fasting the low satiety phenotype are particularly poor at detecting their appetite sensations. This notion is consistent with the findings of previous research conducted by Barkeling et al (2005). However, while all participants in the current study were regular breakfast consumers,

this was based on self-report and habitual consumption was not measured. It is therefore not possible to know whether the low satiety phenotype typically consume a small breakfast which could account for the lower levels of baseline hunger.

Another finding of the current study was that low SQ was associated with higher resting metabolic rate. This finding may help to explain the higher energy intake demonstrated by the low satiety phenotype. While not statistically significant the low satiety phenotype had a higher resting metabolic rate and a higher fat free mass (the largest contributor to RMR) compared to the high satiety phenotype. Research has suggested that resting metabolic rate may be a functionally relevant biological signal for energy need and therefore act as a driver of food intake (Blundell et al., 2012). The greater resting metabolic rate observed in the low satiety phenotype may indicate a greater biologically based drive to eat. It is important to note that the fixed energy breakfasts provided to participants in the current study were individually calibrated based on measured energy requirements. Therefore, the weak satiety response to the breakfast displayed by the low satiety phenotype was not simply a result of differences in energy needs between participants not being accounted for.

Finally, the current study did not find that low satiety responsiveness was associated with a higher BMI. It may be that weakened satiety responsiveness becomes more important for weight gain later in life. This notion should be investigated further. A recent study investigating the effect of energy restriction in the low satiety phenotype reported that similar weight loss was observed between the low and high satiety phenotype groups (Drapeau et al., 2019).

The current study was not without limitations and these should be considered. Firstly, the method used to characterise the high and the low satiety phenotypes, resulted in a small sample size and therefore the findings of the current study should be sought to be replicated in a larger sample. However, it is worth noting that the findings of the current study are consistent with those of previous work, which strengthens confidence in their reliability (Drapeau et al., 2007; Drapeau et al., 2013) In addition, the current study only examined satiety responsiveness in female participants therefore the findings may not be generalisable to males. In addition, the cross sectional nature of the current study means it is not possible to infer the specific cases behind the low satiety phenotype. For instance, it is not known whether eating behaviour traits such as Disinhibition lead to weakened satiety responsiveness, or whether instead weakened satiety responsiveness leads to more opportunistic eating such as snacking. The current study identified the low satiety

phenotype based on the response to four fixed energy breakfast that differed in energy load, energy density (the higher RMR conditions were more energy dense) and macronutrient content (the 25%, 30% and 35% RMR conditions had a higher fat and protein content due to the greater almond content). While this demonstrates the reliability of the SQ as a measure of satiety responsiveness across different energy loads, this could be further improved upon by holding the macronutrient content of the fixed energy breakfast constant. In contrast, future work could manipulate the macronutrient composition of study foods to examine whether the low satiety phenotype exhibit a weakened satiety response to all foods. Or whether foods that have been designed to have a high satiating impact, such as those high in protein or low in fat (Poortvliet et al., 2007) alter the satiety responsiveness of the low satiety phenotype. This may present as an effective nutritional strategy for such individuals.

In conclusion, the current study reliably identified individuals who were either high or low in satiety responsiveness. These individuals, the low satiety phenotype, are characterised by distinct behavioural and psychological characteristics that may increase their susceptibility to overeating, compared to the high satiety phenotype.

Chapter 7

Evaluation of the Influence of different Snack Foods on Appetite Control in the Low Satiety Phenotype.

7.1   Abstract

Background: Some individuals exhibit a weak satiety response to food and as a result may be susceptible to overconsumption. Snack foods can be substantial contributors to daily energy intake; however different types of snacks vary markedly in their impact on satiety per calorie consumed. The purpose of the present study was firstly to identify individual differences in satiety responsiveness; then evaluate the effects of consuming different snack foods on measures of appetite and food hedonics in women classified as weak or strong satiety responders.

Methods: In a crossover design, 42 female participants (age: 25.6 ±7.9; BMI: 22.0 ±2.0) consumed three different mid-morning snacks: raw almonds, savoury crackers or water. Appetite sensations, energy intake, food reward, craving and perceptions of the snack foods were assessed under controlled laboratory conditions. Satiety responsiveness and a distinct satiety phenotype were determined using the satiety quotient.

Results: The low satiety phenotype reported greater levels of hunger, desire to eat and prospective consumption. In addition, they consumed more energy and reported greater craving for sweet foods compared to the high satiety phenotype. Compared to water consuming a mid-morning snack resulted in a lower overall hunger drive and a supressed hedonic preference (implicit wanting) for high fat foods. While participants consumed a greater total amount of calories in the cracker condition compared to the water condition, total energy intake did not differ significantly between the almond condition and the water condition. Almonds were perceived as healthier and more filling compared to the crackers and rated higher with regards to aiding successful weight management. Finally, consumption of almonds had a greater satiating efficiency in the low satiety phenotype compared to crackers.

Conclusion: Weak satiety responsiveness is a reliable trait which can be identified using the satiety quotient. The low satiety phenotype appears to be characterised by behavioural and psychological factors associated with risk of overeating, which is consistent with previous findings of the current thesis. Substituting certain snack foods is one strategy to improve appetite control in the low satiety phenotype.

7.2   Introduction

Foods which promote satiety have received increasing attention over recent years as satiating foods can help consumers control their appetite, eat healthily and manage their weight (Halford & Harrold 2012). Importantly, research demonstrates that calorie for calorie not all foods provide the same level of satiety (Holt et al., 1995); and a hierarchy of macronutrient satiating power has been established (Blundell & Macdiarmid 1997; Stubbs et al., 2000) with foods that are high in protein and fibre, and low in energy density being more satiating (Paddon-Jones et al., 2008; Clark & Slavin 2013; Rolls, Drewnowski & Ledikwe 2005). Furthermore, how an individual perceives a food (i.e. as a health food or low in calories/fat) has been shown to influence food choice and acceptance (Costell et al., 2010) and expectations of satiety (Buckland et al. 2015).

In recent years there has been a significant increase in snacking behaviour (Piernas & Popkin 2010) with snack foods now contributing considerably more to total daily energy intake (Duffey & Popkin 2011). Interestingly, increase in snacking has occurred alongside the rise in obesity. However, it has been suggested that the relationship between increased snacking and obesity may be attributed to the types of foods typically consumed as a snack (Ortinau et al. 2014). Snack foods have been characterised as having poor nutritional quality, with most consisting primarily of fats and carbohydrates (Zizza & Bu., 2012). If additional energy consumed from snacks is not appropriately compensated for then frequent snacking can contribute to excess energy intake (Miler et al., 2013). On the other hand, studies have demonstrated that frequent snacking can promote consistent feelings of satiety throughout the day and as a result lead to less overeating and improved daily energy balance (Leidy & Campbell 2011). Therefore, snacking is not an undesirable behaviour in itself as it can increase the opportunity for the addition or substitution of healthy foods into the diet (Hartmann et al., 2013).

Almonds are a natural food product, which are high in both protein and fibre and relatively low in digestible energy (Novotny et al., 2012). It is well established that

proteins and fibres have prominent effects on appetite control (Fromentine et al., 2012; Clark & Slavin 2013) and since they act via different mechanisms their effects may be additive. Therefore, the unique structural properties and macronutrient composition of whole raw almonds may be beneficial for the control of hunger, strength of satiety and subsequent energy intake relative to other forms of high energy snack food. While the exact mechanisms through which almonds might act upon appetite are unknown there is some evidence that consumption of almonds can have favourable effects on appetite control. Long-term studies have revealed that daily almond consumption does not result in significant weight change (Fraser et al., 2002; Sabate 2003; Hollis & Mattes 2007; Tan & Mattes 2013). In addition, acute studies have demonstrated that the addition of almonds to a meal decreases blood glucose concentrations and increases satiety in healthy adults (Jenkins et al., 2006; Josse et al., 2007) and in those with impaired glucose tolerance (Mori et al., 2011). Almonds as a snack have been found to reduce both self-reported hunger and desire to eat (Tan & Mattes 2013). In a recent study a mid-morning snack of almonds (28g and 42g) was tested against a negative control of no almonds (Hull et al., 2014). The authors found a portion dependent effect of almonds on subjective reports of appetite and subsequent ad libitum energy intake and overall good compensation for the calories from almonds. Consequently, the authors concluded that almonds can be a healthy snack option. To date no acute studies have objectively assessed whether snacking on almonds leads to changes in subjective reports of appetite, subsequent objectively assessed energy intake or food hedonics (liking and wanting for food), when compared to a comparator snack which is matched for both energy and weight.

7.2.1 Study Aims

The purpose of the present study was firstly to identify individual differences in satiety responsiveness, then to compare the effect of consuming different energy-matched snack foods or water on measures of appetite and food hedonics in women classified as low or high satiety phenotypes using the satiety quotient. Based on previous research in this thesis it was hypothesised that the low satiety phenotype would be characterised by behavioural, psychological and physiological risk factors for overconsumption. In addition, snack foods with differing nutrient profiles may modulate appetite and subsequent food intake in the low satiety phenotype.

7.3   Method

7.3.1   Participants

Forty-two healthy females (Age: 26±7.9, BMI: 22±2.0) were recruited via a University of Leeds email distribution list, to which staff and students, as well as members of the public are able to sign up to. The recruitment email included information about the study, the inclusion criteria and a screening questionnaire which was used to determine eligibility. Inclusion criteria for the study included: aged between 18-55 years and BMI between 18.5-30kg/m². Participants who were taking medication known to affect appetite, currently dieting to lose or maintain weight, not regular breakfast consumers, smokers, reported a history of eating disorders or were unfamiliar with or disliked the study foods were excluded. Eligible participants were invited to a screening session at the Human Appetite Research Unit, to confirm eligibility and to have the study procedure presented to them. All participants provided written informed consent and all study procedures were reviewed and approved by the University of Leeds, School of Psychology Ethics Committee (*15-0269*).

7.3.2   Design

The study followed a randomised, counterbalanced, repeated measures design. Each participant attended the Human Appetite Research Unit at the University of Leeds on four occasions: this included a screening and measures session and three experimental sessions. Each study session was scheduled at least seven days apart. For all visits, participants were required to refrain from eating or drinking anything besides water from 10pm the evening before to ensure a standardised fasting state and to abstain from drinking alcohol or engaging in physical activity for 24 hours prior to the session. Compliance with this instruction was assessed at the beginning of each session by self-report. During the experimental sessions participants consumed breakfast, lunch, dinner and a mid-morning snack at the research unit, participants were permitted to leave the unit in between meals but were instructed not to eat or drink anything besides water. Ratings of subjective appetite were taken at regular intervals throughout the test day using a validated hand-held Electronic Appetite Rating System (EARS-II). The breakfast test meal served to participants was fixed and individually calibrated to provide 25% of their resting energy requirement. This enabled the satiety quotient (SQ) to be calculated and satiety responsiveness to be determined for each participant. An ad libitum lunch and dinner test meal was used to assess energy intake. The Control of Eating Questionnaire and the Leeds Food Preference Questionnaire were used to assess food craving and

reward. Furthermore, measures of appetite in individuals classified as weak or strong satiety responders were compared, following the consumption of snack foods (almonds/savoury crackers) which vary nutritionally in their satiating potential.

7.3.3 Measures

All measures were conducted within the HARU at the University of Leeds with the exception of the initial screening questionnaire, which was completed online.

7.3.3.1 Online Screening Questionnaire

An online screening questionnaire was used to identify participants based on the inclusion and exclusion criteria. Suitable participants were sent a copy of the participant information sheet and invited to attend a screening and measures session.

7.3.3.2 Resting Metabolic Rate

Resting metabolic rate was measured using an indirect calorimeter fitted with a ventilated hood (GEM; Nutren Technology Ltd); this measure is described in greater detail in Chapter 3. Participants' resting metabolic rate was assessed during the measures session, and was used to calibrate the fixed energy breakfast served to participants; which was proportional to 25% of their resting energy requirement.

7.3.3.3 Anthropometrics and Body Composition

Standing height was measured to the nearest 0.5cm using a stadiometer, body weight was measured to the nearest 0.1kg using an electronic balance and waist circumference was measured at the participants' naval after expiration. Body composition (fat mass, fat free mass and percentage body fat) was assessed using air plethysmography (BodPod, Concord, CA, USA). All anthropometric and body composition measures were conducted during the measures session and are described in more detail in Chapter 3.

7.3.3.4 Eating Behaviour Questionnaires

Participants completed a number of eating behaviour questionnaires during the measures session, including the Three Factor Eating Questionnaire (TFEQ; Stunkard & Messick, 1985) to assess levels of restraint, disinhibition and hunger; Control of Eating Questionnaire (CoEQ; Hill et al., 1991) to measure mood, appetite and experience of food craving and Binge Eating Scale (BES; Gormally et al., 1982) to assess the severity of binge eating. These questionnaires are described in further detail in Chapter 3.

7.3.3.5 Subjective Appetite Sensations

Subjective appetite (hunger, fullness, desire to eat and prospective consumption) was assessed using 100-mm VAS presented on an Electronic Appetite Rating System (EARS-II). These measures are described in more detail in Chapter 3. Ratings of subjective appetite were completed at baseline, every 30 minutes until the mid-morning snack, then every 60 minutes, as well as before and after each event in the procedure.

7.3.3.6 Energy Intake

7.3.3.6.1 Fixed Energy Breakfast

The fixed energy breakfast served to participants comprised of muesli, raisins and sultanas combined with natural yoghurt and honey. The macronutrient content of the breakfast was fixed at 62% carbohydrate, 22% fat and 15% protein (see Table 1 for details), but was individually calibrated to provide participants with 25% of the individual energy requirements. Breakfast was served alongside either tea, coffee or water and participants were given 15 minutes to consume the breakfast in its entirety.

Table 7.1. Nutritional composition of the fixed energy breakfast food items.

Breakfast Item	KCAL/100g	CHO/100g	FAT/100g	PRO/100g
Neal's Yard Muesli Base	360.0	70.0	5.0	13.0
Neal's Yard Raisins	268.6	69.3	0.0	2.1
Neal's Yard Sultanas	274.7	69.4	0.4	2.7
Yeo Valley Natural Yoghurt	82.0	6.5	4.2	4.6
Sainsbury's Runny Honey	319.5	84.3	0.2	0.4
Semi-skimmed Milk	50.0	4.8	1.1	3.6

7.3.3.6.2 Mid-Morning Snack

Participants were served either almonds, savoury crackers or water (which acted as a no-energy control) as a mid-morning snack. The mid-morning snack was individually calibrated; each participant was provided with 0.9g of snack item per kg of their body weight - this quantity was pre-determined in a pilot study as being most appropriate. The snack items were matched for both energy and weight (see Table 2 for details for the nutritional composition). The amount of water provided alongside the snack was adjusted so that the total weight of the snack and water consumed equalled 300g. The snack was served to participants two hours following breakfast, and participants were given 15

minutes to consume the snack in its entirety. Despite recent research suggesting that the energy value of almonds may be lower than that of the current Atwater value (Novotny et al., 2012; Grundy et al., 2015a; Grundy et al., 2015b) here we have used the 595kcal per 100g or standard Atwater energy value for the almonds.

Table 7.2. Nutritional composition of the mid-morning snack.

Snack Item	KCAL/ 100g	CHO/ 100g(%)	FAT/ 100g(%)	PRO/ 100g(%)
Almonds	595	9.1 (5.7)	49.9 (75.5)	21.2 (14.2)
Sainsbury's Savoury Crackers	581	38.3 (24.7)	40.6 (62.9)	14.2 (9.8)

7.3.3.6.3 Ad Libitum Energy Intake

Ad libitum energy intake was assessed at both the lunch and the dinner test meals. On both occasions participants were instructed to consume as much or as little as they wanted, but to eat until they reached a comfortable level of fullness. Food was weighed pre- and post- consumption to the nearest 0.1g to determine energy intake. The lunch test meal consisted of tomato and herb risotto and strawberry yoghurt (see Table 3 for details) and was served four hours following breakfast. The dinner test meal consisted of chili con carne and rice, salad items, garlic bread and chocolate brownies (see Table 4 for details) and was served four hours following lunch. Free-living ad libitum snack food intake was also assessed using a snack box which participants took away with them at the end of each experimental session (see Table 5 for details). Participants were informed that they could consume as much or as little as they wanted, but that they should not share, give away or dispose of any of the food items. Any uneaten food items, including the packaging, were returned to the research unit the following day.

Table 7.3. Serving size (g) and nutritional composition of the lunch food items.

Lunch Item	Serving (g)	KCAL/ 100g	CHO/ 100g	FAT/ 100g	PRO/ 100g
Uncle Bens Tomato & Herb Risotto	900	178	31.4	3.9	3.7
Sainsbury's Olive Oil	45	823	0.5	91.5	0.5
Yeo Valley Strawberry Yoghurt	425	106	13.2	3.8	4.7
Sainsbury's Double Cream	45	439	1.5	47.5	1.5

Table 7.4. Serving size (g) and nutritional composition of the dinner food items.

Dinner Item	Serving (g)	KCAL/ 100g	CHO/ 100g	FAT/ 100g	PRO/ 100g
Stagg Chilli Con Carne	650	130	13.0	5.0	7.0
Uncle Bens Basmati Rice	250	153	30.9	1.6	3.3
Sainsbury's Garlic Bread	200	362	36.9	20.7	5.6
Sainsbury's Lettuce	50	14	1.9	0.3	0.7
Sainsbury's Tomatoes	115	20	3.1	0.5	0.7
Sainsbury's Cucumber	115	10	1.5	0.1	0.7
Thornton's Chocolate Brownies	140	437	56.1	20.4	6.0

Table 7.5. Serving size (g) and nutritional composition of the snack box items.

Snack Item	Serving (g)	KCAL/ 100g	CHO/ 100g	FAT/ 100g	PRO/ 100g
Sainsbury's Red Apple	1	46.8	11.8	0.1	0.4
Sainsbury's Mandarin Orange	2	40.7	8.7	0.5	0.9
Sainsbury's Ham	60g	119.7	1.4	2.8	22.3
Sainsbury's Grated Cheese	75g	389.0	1.7	31.4	25.0
Hovis Best of Both	4 slices	212.1	40.4	2.2	10.2
Walkers Ready Salted Crisps	24g	126.4	12.9	8.0	1.5
Cadbury's Chocolate Buttons	50g	516.8	56.5	30.5	7.6
Muller Vanilla Yoghurt	1 pot	46.6	7.5	0.1	4.4

7.3.3.7 Leeds Food Preference Questionnaire

The Leeds Food Preference Questionnaire (LFPQ) was used to assess explicit liking and implicit wanting for a selection of food images (selected to be predominantly high or low in fat) prior to the lunch test meal. The LFPQ is described in detail in Chapter 3.

7.3.3.8 Perception of Snack Foods Questionnaire

At the end of the study participants completed a questionnaire that assessed their perceptions and habitual consumption of the snack foods included in the study. Participants were required to respond to a series of questions using a 7-point Likert scale. For instance, 'To what extent do you think this snack is healthy' and 'Generally how

filling do you consider this snack to be'; all questions were anchored at each end with 'Not at all' and 'Extremely'. See Table 6 for questions included in questionnaire.

Table 7.6. The questions included in the perceptions questionnaire.

How strong is your desire to eat more?
How difficult was it to consume the snack?
How suitable was the portion size?
How much more could you eat of the snack?
How often do you consume this kind of snack?
How pleasant was the taste of the snack?
To what extent do you think the snack is healthy?
To what extent do you think the snack is high fat?
To what extent do you think the snack is high calorie?
How filling do you consider the snack to be?
To what extent do you associate this snack with successful weight management?
To what extent do you associate this snack with consuming too much?

7.3.3.9 Satiety Quotient

Visual analogue scale ratings for Hunger were used to calculate SQ for the 75-min period post breakfast. SQ was then used to characterise participants as high or low in satiety responsiveness. The Satiety Quotient is described in greater detail in Chapter 3.

The following formula was used to calculate SQ:

$$SQ \text{ (mm/kcal)} = \left(\frac{\text{rating before eating} - \text{mean of the 75-min post meal ratings}}{\text{energy content of the test meal (kcal)}} \right) \times 100$$

7.3.4 Procedure

For all sessions participants arrived at the research unit following an overnight night fast. Participants were instructed not to consume alcohol or engage in physical activity for 24-hours and not to consume caffeine for 12-hours prior to the sessions. For the screening and measures session participants arrived at the research unit between 7.00am-9.00am. First, participants eligibility was confirmed, they were then provided with a written and verbal explanation of the research requirements and were given the opportunity to ask any questions before providing written informed consent. Height, weight, waist circumference, resting metabolic rate and body composition were measured. Participants

also completed a number of eating behaviour questionnaires (TFEQ, CoEQ, BES). For the experimental session participants arrived at the research unit between 8.00am-9.00am. On arrival participants were shown to a research cubicle where they completed the first set of VAS ratings and consumed breakfast. Following breakfast a second set of VAS ratings were completed and participants were free to leave the research unit but were asked to return two hours later for the mid-morning snack. During this time the EARS-II prompted completion of the VAS ratings at 30-minute intervals. Two hours after breakfast participants completed a set of VAS ratings and were served the mid-morning snack. Participants completed another set of VAS ratings following the mid-morning snack and were once again free to leave the research unit. This time participants were asked to return 1 hour and 50 minutes later for lunch and the EARS-II prompted completion of the VAS ratings at 60-minute intervals. During the lunchtime session, participants completed the LFPQ twice, once before lunch and again after. Participants completed VAS ratings before and after each event in the lunchtime procedure. Following lunch participants were free to leave the research unit but were asked to return 4 hours later for dinner. Participants continued to completed VAS ratings prompted by the EARS-II at 60-minute intervals while away from the research unit. Participants completed VAS ratings before and after the dinner test meal. Following dinner and before leaving the research unit for the day participants collected their snack boxes. Participants completed two more sets of VAS ratings that evening, as well as the Control of Eating Questionnaire. The following experimental sessions were identical apart from the mid-morning snack served to participants. On completion of all sessions participants completed an Exit Questionnaire; then received a debrief and were compensated for taking part. See Table 7 for a schedule of the VAS ratings completed and Figure 1 for a schematic representation of the study procedure.

Table 7.7. Schedule of VAS ratings taken across the test day procedure.

Rating	Event	Time
1	Baseline	-5minutes
2	Post-Breakfast	+15minutes
3	Completed away from HARU	+30minutes
4	Completed away from HARU	+60minutes
5	Completed away from HARU	+90minutes
6	Pre-Snack	+120minutes

7	Post-Snack	+135minutes
8	Completed away from HARU	+180minutes
9	Pre-LFPQ	+230minutes
10	Post-LFPQ/Pre-Lunch	+240minutes
11	Post-Lunch	+270minutes
12	Post-Lunch	+280minutes
13	Completed away from HARU	+300minutes
14	Completed away from HARU	+360minutes
15	Completed away from HARU	+420minutes
16	Pre-Dinner	+480minutes
17	Post-Dinner	+510minutes
18	Completed away from HARU	+540minutes
19	Completed away from HARU	+600minutes
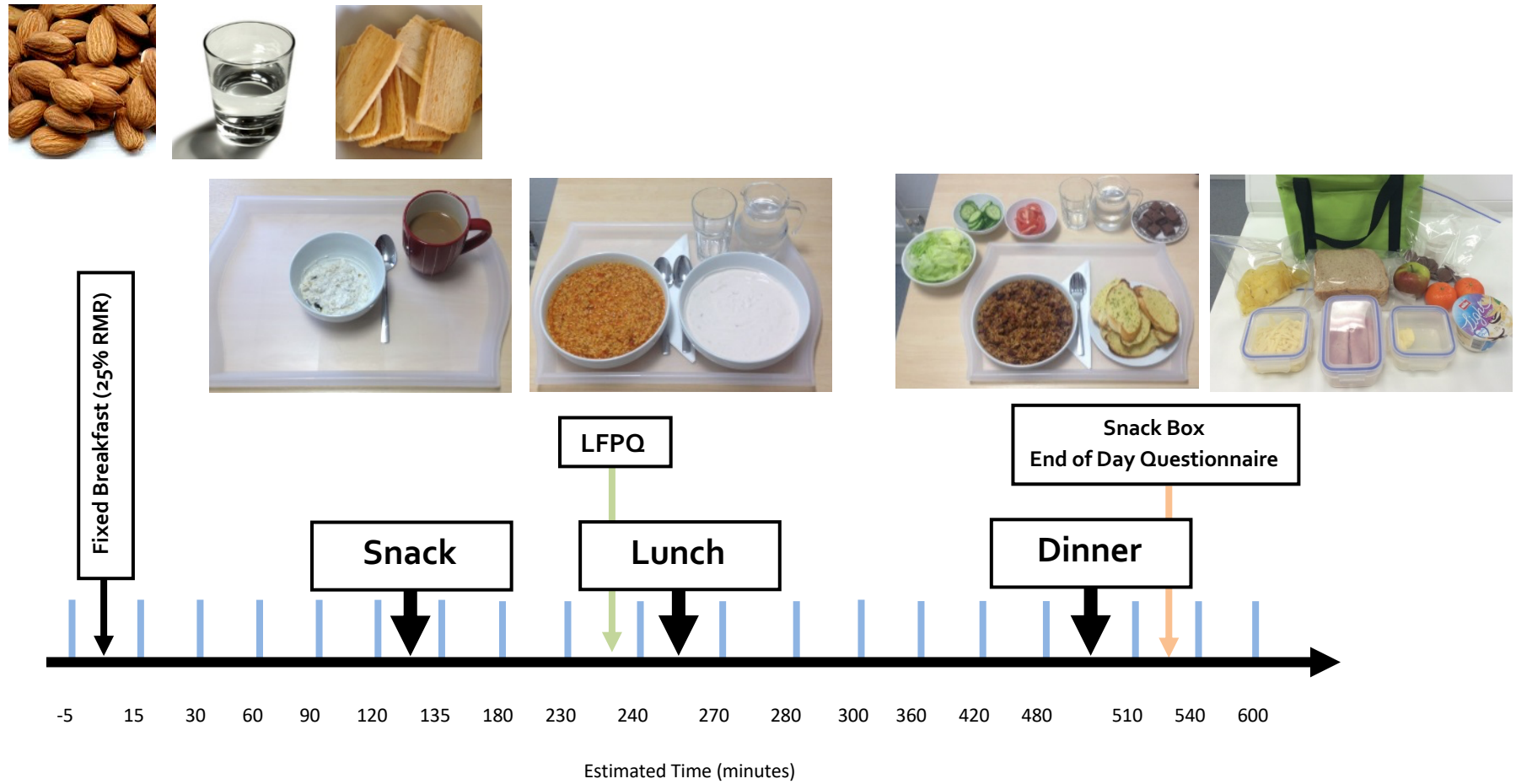
Figure 7.1 Schematic representation of study procedure; experimental session.

7.3.5   Data Analysis

Data was analysed using Statistical Programme for Social Sciences (SPSS) Version 22. Pearson correlation coefficients were used to assess the relationship between physiological, psychological and behavioural variables and the SQ. Reliability of the satiety quotient as a measure of satiety responsiveness was assessed by comparing SQ across experimental sessions using Pearson correlation coefficients. Participants were then characterised according to individual satiating efficiency using average SQ for the 75-minute period following breakfast and a tertile split to identify high and low cut off points. Independent t-tests were used to compare scores on baseline measures (physiological, psychological and behavioural) for the high and the low satiety phenotype. To assess whether the consumption of different snack items results in different patterns of subjective appetite (hunger, fullness, desire to eat and prospective consumption) in the high and the low satiety phenotype 3x19x2 Mixed ANOVAs were conducted, with snack condition and time as within subject factors and satiety phenotype as the between subjects factors. To assess the interaction between snack condition and satiety phenotype on measures of energy intake and food hedonics (including the CoEQ and LFPQ) 3x2 Mixed ANOVAs were conducted, with snack condition as the with subjects factor and satiety phenotype as the between subjects factor. To assess the interaction between snack condition and satiety phenotype on SQ of the mid-morning snack over time a 3x3x2 Mixed ANOVA was conducted, with snack condition and time and as within subject factors and satiety phenotype as the between subjects factor. Finally, paired sample t-tests were used to assess the palatability and perception ratings of the mid-morning snacks. For all analyses an α-level of .05 was used to determine statistical significance. Where appropriate Greenhouse-Geisser probability levels were used to adjust for non-sphericity. Where significant effects were obtained post hoc analyses with Bonferroni correction for multiple comparisons were conducted. Cohen's d was used as a measure of effect size.

7.4   Results

7.4.1   Participant Characteristics

Table 7.8. Mean (standard deviation) and range for age, anthropometrics, body composition and psychometric trait characteristics for the overall sample.

	Mean (SD)	Range
Age (years)	25.6 (7.9)	18.0 – 54.0
Weight (kg)	58.5 (6.1)	45.2 – 74.9
BMI (kg/m^2)	22.0 (2.0)	18.8 – 29.3
Waist (cm)	73.5 (5.6)	65.0 – 89.3
Fat mass (kg)	15.5 (5.0)	6.0 – 29.0
Fat free mass (kg)	43.0 (4.1)	32.4 – 54.0
Body fat (%)	26.0 (6.6)	10.7 – 40.6
TFEQ Restraint	9.4 (4.8)	0.0 – 19.0
TFEQ Disinhibition	7.6 (2.8)	2.0 – 13.0
TFEQ Hunger	6.1 (3.2)	0.0 – 13.0
Binge Eating Score	10.1 (5.7)	0.0 – 26.0

7.4.2 Validity of the SQ as a Marker of Susceptibility

Average SQ across the study visits was negatively associated with resting metabolic rate ($r(42) = -0.329$, $p<0.05$) and energy intake ($r(42) = -0.348$, $p<0.05$); and positively associated with age ($r(42) = 0.389$, $p<0.05$), TFEQ flexible restraint ($r(42) = 0.307$, $p<0.05$) and baseline hunger ($r(42) = 0.538$, $p<0.001$). These preliminary associations suggest that a low SQ is associated with risk factors for overconsumption. To explore this further we categorised participants as high or low in satiety responsiveness.

Table 7.9. Correlational matrix for average SQ, age, RMR, TFEQ flexible restraint, average energy intake and average baseline hunger for the overall sample.

	Age	RMR	TFEQ-FR[2]	Energy Intake[1]	Baseline Hunger[1]
SQ(mm/kcal)[1]	.389*	-.329*	.307*	-.348*	.538**
Age	-	-.092	.272	-.243	.111
RMR		-	-.241	.310*	.023
TFEQ-FR[2]			-	-.270	.339*
Energy Intake				-	-.078
Baseline Hunger					-

Note: [1]Average collapsed across study visits; [2]Flexible Restraint. *p<0.05; **p<0.01.

7.4.3 Categorisation and Characterisation of Satiety Phenotypes

To categorise participants according to satiety phenotypes, satiety quotient for the 75-minutes period following each breakfast was calculated and an average across the three visits was determined for each participant. A tertile split was then used to calculate high and low cut-off points. The low satiety phenotype were identified as those who had a SQ ≤ 10.9 (n, 14), whereas the high satiety phenotype were identified as those who had a SQ ≥ 14.7 (n, 14). Fourteen participants were not categorised, these were not included in any subsequent analysis, but their characteristics are shown in Table 10 for completeness. Table 10 shows the participant characteristics for the low and the high satiety phenotypes. As designed the low satiety phenotype had a significantly lower SQ across the study visits compared to the high satiety phenotype (t(26) = 9.4, p<0.001, d = 3.6). In addition, the low satiety phenotype reported lower baseline hunger (t(26) = 3.1, p<0.01, d = 1.2) and desire to eat (t(26) = 2.3, p<0.05, d = 0.8) and were younger (t(14) = 2.8, p<0.05, d = 1.1) compared to the high satiety phenotype.

Table 7.10. Mean (standard deviation) satiety quotient, appetite sensations, age, anthropometrics, body composition, resting metabolic rate and psychometric trait characteristics for the low and high, and the uncategorised, satiety phenotypes.

	Low Satiety Phenotype (n, 14)	High Satiety Phenotype (n, 14)	Uncategorised (n, 14)
SQ (mm/kcal)[1]	6.6 (3.2)***	18.9 (3.7)***	12.8 (1.0)
Hunger (mm)[2]	54.6 (18.0)**	71.4 (9.2)**	65.1 (16.7)
Fullness (mm)[2]	23.6 (10.9)†	14.9 (11.6)†	18.1 (13.9)
Desire to Eat (mm)[2]	59.1 (17.1)*	71.5 (11.3)*	63.7 (17.5)
Prospective Consumption (mm)[2]	51.4 (18.2)	57.3 (17.1)	55.8 (18.6)
Age (years)	21.1 (1.8)*	29.9 (11.7)*	26.0 (4.1)
Height (cm)	162.9 (7.6)	164.0 (5.2)	162.5 (4.5)
Weight (kg)	56.8 (6.8)	58.7 (4.4)	59.9 (6.7)
BMI (kg/m^2)	21.3 (1.5)	21.9 (1.6)	22.7 (2.6)
Waist (cm)	72.4 (5.7)	73.8 (5.7)	74.3 (5.7)
Fat mass (kg)	13.7 (4.7)	15.7 (3.6)	16.9 (6.2)
Fat free mass (kg)	43.1 (5.1)	42.9 (2.8)	43.0 (4.1)
Body fat (%)	23.8 (6.6)	26.5 (4.8)	27.8 (8.0)
Resting Metabolic Rate (kcal)	1344.1 (192.8)	1251.3 (128.3)	1356.5 (169.2)

TFEQ Restraint	7.7 (4.5)	9.9 (4.4)	10.4 (5.3)
TFEQ Disinhibition	7.5 (2.7)	7.8 (2.7)	7.6 (3.3)
TFEQ Hunger	6.4 (3.2)	6.1 (3.8)	5.8 (2.6)
Binge Eating Score	9.6 (5.0)	11.2 (7.1)	9.4 (4.9)

Note: Comparisons made between LSP and HSP *p<0.05, **p<0.01, ***p<0.001; †p=0.05; [1]Average SQ collapsed across study visits; [2]Average baseline hunger, fullness, desire to eat and prospective consumption, collapsed across study visits.

7.4.4 Subjective Appetite Sensations
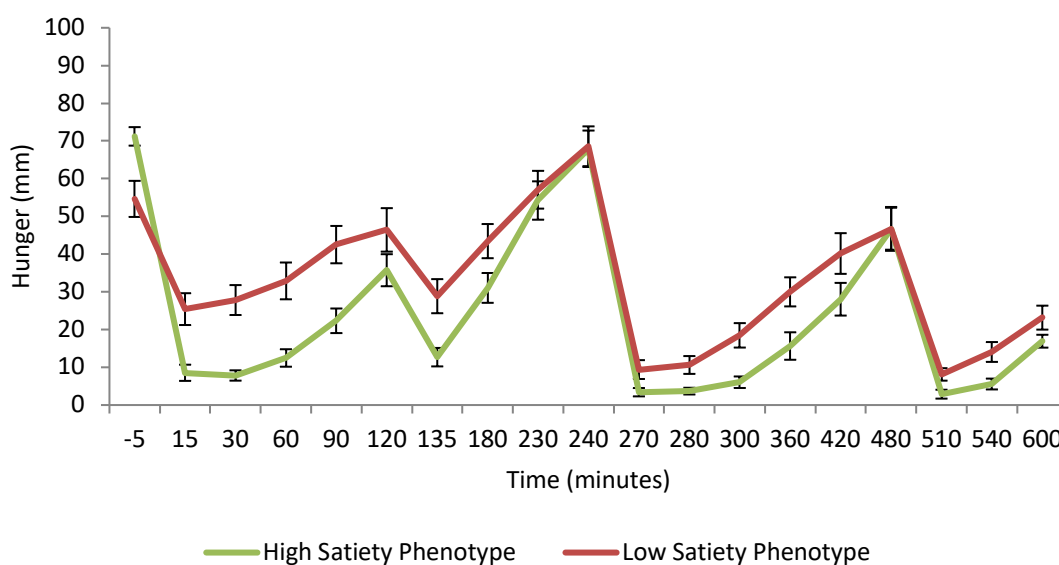
Figure 7.2. Ratings of hunger for the high and low satiety phenotypes, across the test day. Note: Ratings collapsed across study visits; *p<0.05; **p<0.01; ***p<0.001.

There was a main effect of snack condition on ratings of hunger, desire to eat, prospective consumption and fullness [$F_{(2, 52)} = 10.2$, $p<0.001$; $F_{(1.5, 40.7)} = 16.5$, $p<0.001$; $F_{(1.5, 38.6)}$ 10.1, $p<0.01$; $F_{(2, 52)} = 8.91$, $p<0.001$, respectively] across the test day, with greater levels of fullness and lower levels of hunger, desire to eat and prospective consumption in the almond condition compared to the water condition [$p<0.001$, $d = 0.5$; $p<0.001$, $d = 0.6$; $p<0.001$, $d = 0.8$; $p<0.001$, $d = 0.6$, respectively] and in the cracker condition compared to the water condition [$p<0.05$, $d = 0.4$; $p<0.05$, $d = 0.4$; $p<0.01$, $d = 0.5$; $p<0.01$, $d = 0.4$, respectively]. In addition, there was a main effect of satiety phenotype on ratings of hunger, desire to eat, prospective consumption and fullness [$F_{(1, 26)} = 5.61$, $p<0.05$; $F_{(1, 26)} = 4.61$, $p<0.05$; $F_{(1, 26)} = 6.61$, $p<0.05$; $F_{(1, 26)}$ 11.6, $p<0.01$, respectively] across the test day with the low satiety phenotype reporting lower levels of fullness and greater levels of hunger, desire to eat and prospective consumption

compared to the high satiety phenotype [p<0.01, d = 1.4; p<0.05, d = 0.9; p<0.05, d = 0.8 ; p<0.05, d = 1.0, respectively]. However, there was no interaction between snack condition and satiety phenotype on ratings of hunger [$F_{(2, 52)}$ = 1.87, p = .16], desire to eat [$F_{(1.5, 40.7)}$ = .98, p = .38], prospective consumption [$F_{(1.5, 38.6)}$ = 1.09, p = .33] and fullness [$F_{(2, 52)}$ = .100, p = .14].
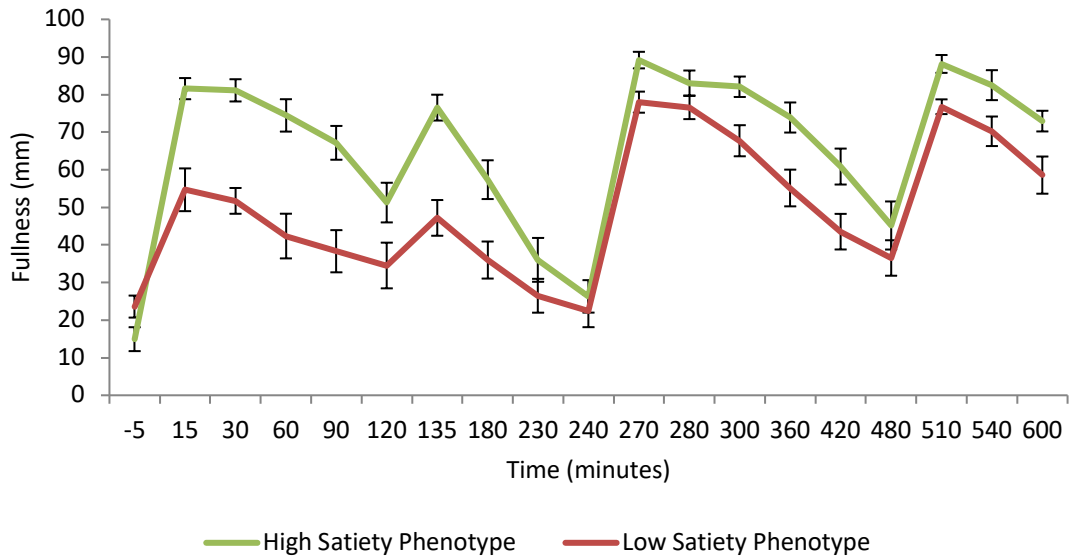
Figure 7.3. Ratings of fullness for the high and low satiety phenotypes, across the test day. Note: Ratings collapsed across study visits; *p<0.05; **p<0.01; ***p<0.001.
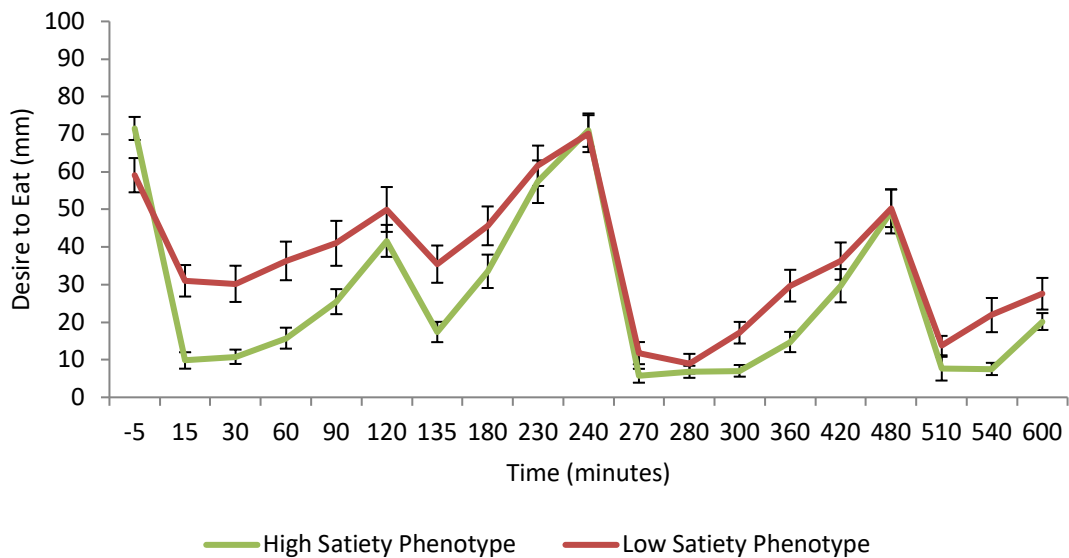
Figure 7.4. Ratings of desire to eat for the high and low satiety phenotypes, across the test day. Note: Ratings collapsed across study visits; *p<0.05; **p<0.01; ***p<0.001.
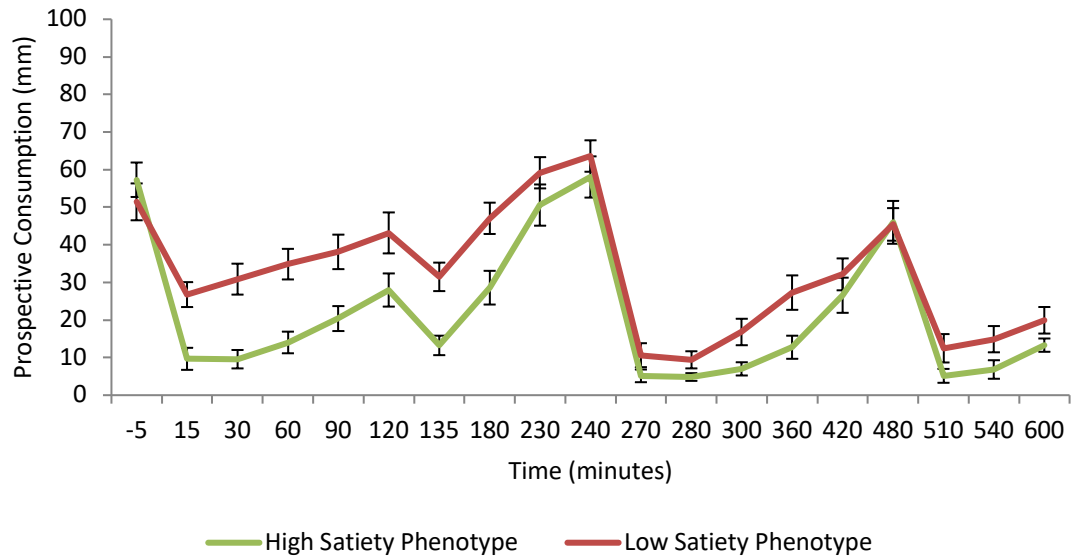
Figure 7.5. Ratings of prospective consumption for the high and low satiety phenotypes, across the test day. Note: Ratings collapsed across study visits; *p<0.05; **p<0.01.

7.4.5 Energy Intake
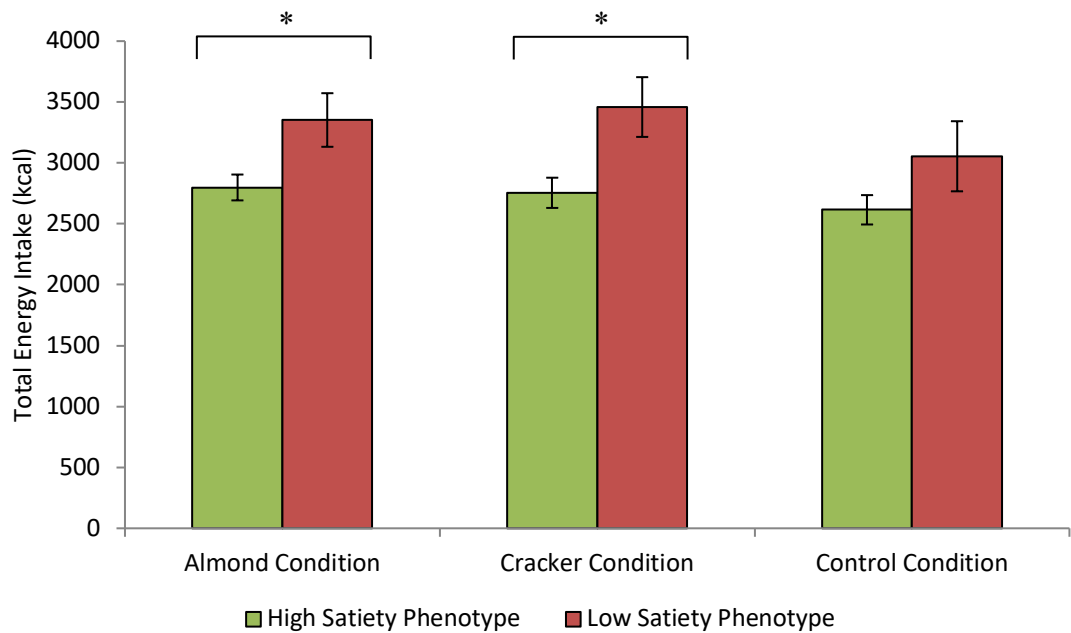
Figure 7.6. Energy intake (kcal) for the high and low satiety phenotypes. Note: *p<0.05.

There was a main effect of snack condition [$F(2, 52) = 4.35$, $p<0.05$] on total energy intake; participants consumed a greater total amount of calories in the cracker condition compared to the water condition ($p<0.05$, $d = 0.3$). Total energy intake did not differ significantly between the almond condition and the water condition. In addition, there was a main effect of satiety phenotype on total energy intake [$F(1, 26) = 5.00$, $p<0.05$]; the low satiety phenotype consumed more energy compared to the high satiety

phenotype. Post hoc analyses revealed that energy intake was significantly different between the low and high satiety phenotype, in both the almond and the cracker snack conditions (p<0.05, d = 0.9; p<0.05, d = 1.0, respectively). However, there was no interaction between snack condition and satiety phenotype [F(2, 52) = .867, p = .45].

7.4.6   Food Hedonics

7.4.6.1   Control of Eating Questionnaire

There were no differences between the low and high satiety phenotype on the Craving Control (t(26) = 1.4, p = .17) Craving for Sweet (t(26) = .18, p = .86) Craving for Savoury (t(26) = 1.9, p = .06) or Positive Mood (t(26) = .57, p = .58) subscales of the CoEQ assessed at baseline using the 7-day CoEQ. However, for the 24-hour CoEQ, there was a main effect of satiety phenotype [F(1, 25) = 4.94, p<0.05] on the Craving for Sweet subscale. The low satiety phenotype reported greater craving for sweet foods compared to the high satiety phenotype (p<0.05, d = 0.9). There was no main effect of snack condition [F(2, 50) = .703, p = .50] or interaction between snack condition and satiety phenotype [F(2, 50) = .673, p = .52] on the Craving for Sweet CoEQ scores.
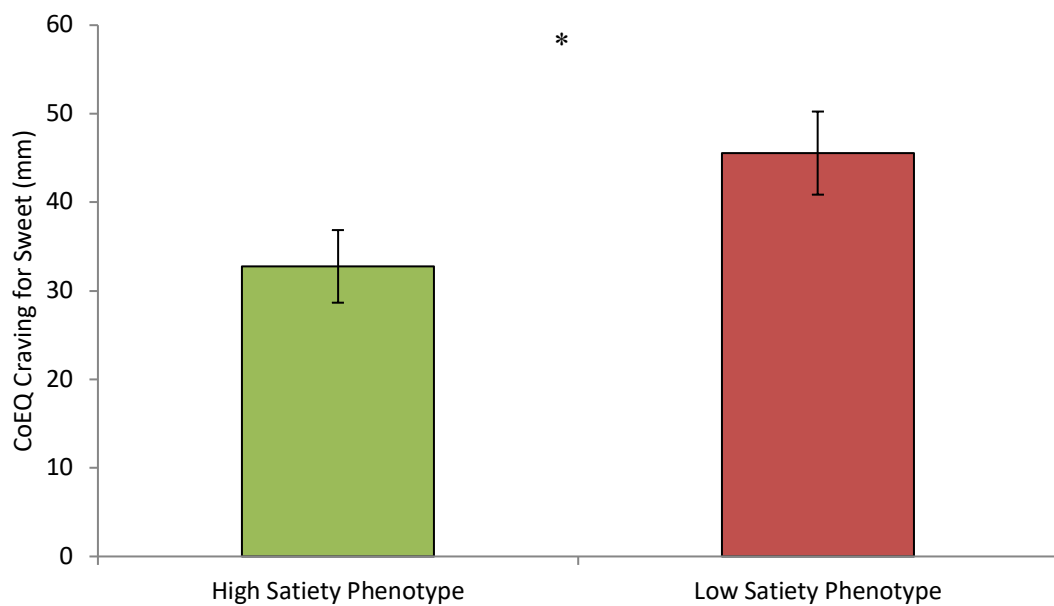
Figure 7.7. Craving for sweet, for the high and the low satiety phenotype. Note: *p<0.05.

7.4.6.2   Leeds Food Preference Questionnaire

There was no main effect of snack condition or satiety phenotype on explicit liking fat appeal bias [F(2, 52) = 2.33, p = .11; F(1, 26) = .088, p = .77, respectively], explicit liking taste appeal bias [F(2, 52) = 1.67, p = .19; F(1, 26) = 2.57, p = .12, respectively], or implicit wanting taste appeal bias [F(1.5, 39.1) = .960, p = .37; F(1, 26) = .107, p = .75,

respectively]. However, while there was no effect of satiety phenotype on implicit wanting fat appeal bias [$F_{(1,26)}$ = .003, p = .96]; there was a main effect of snack condition on implicit wanting fat appeal bias [$F_{(1.2, 31.5)}$ = 3.97, p<0.05]. There was a greater bias towards high fat foods, prior to the lunch test meal, in the control condition compared to both the almond condition (p<0.05 d = 0.2) and cracker condition (p<0.05, d = 0.4). There was no interaction between snack condition and satiety phenotype on explicit liking fat appeal bias, explicit liking taste appeal bias, implicit wanting taste appeal bias or implicit wanting fat appeal bias [$F_{(2, 52)}$ = 1.69, p = .19; $F_{(2, 52)}$ = .335, p = .72; $F_{(1.5, 39.1)}$ = 1.03, p = .35; $F_{(1.2, 31.5)}$ = .121, p = .89, respectively].
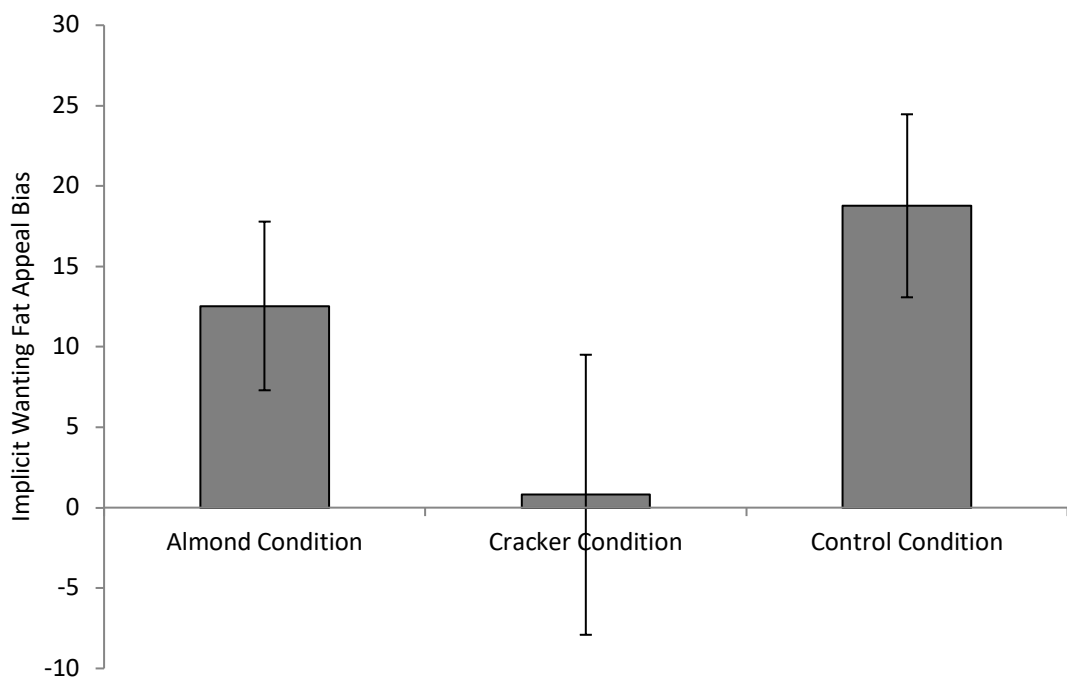
Figure 7.8. Implicit wanting appeal bias for high-fat versus low-fat foods prior to consumption of the lunch test meal. Note: A positive value indicates a bias towards high-fat foods and a negative value indicates a bias towards low-fat foods; *p<0.05.

7.4.7 Satiety Quotient of the Mid-Morning Snack

There was no main effect of snack condition [$F_{(1, 26)}$ = .31, p = .58] or satiety phenotype [$F_{(1, 26)}$ = 1.0, p = .33] on satiety quotient for the mid-morning snack. There was however, a significant main effect of time [$F_{(2, 52)}$ = 62.8, p<0.001], the satiating efficiency of the mid-morning snack decreased over the 120-minute period post consumption. There was no interaction between snack condition and satiety phenotype on satiety quotient for the mid-morning snack [$F_{(1, 26)}$ = 3.36, p = .08]. Post hoc analyses revealed that SQ for the almond snack did not differ significantly between the

high and the low satiety phenotype at any time point following consumption. However, SQ for the cracker snack differed significantly between the high and the low satiety phenotype at 60 minutes post consumption ($p<0.05$, $d = 0.8$).

(a)
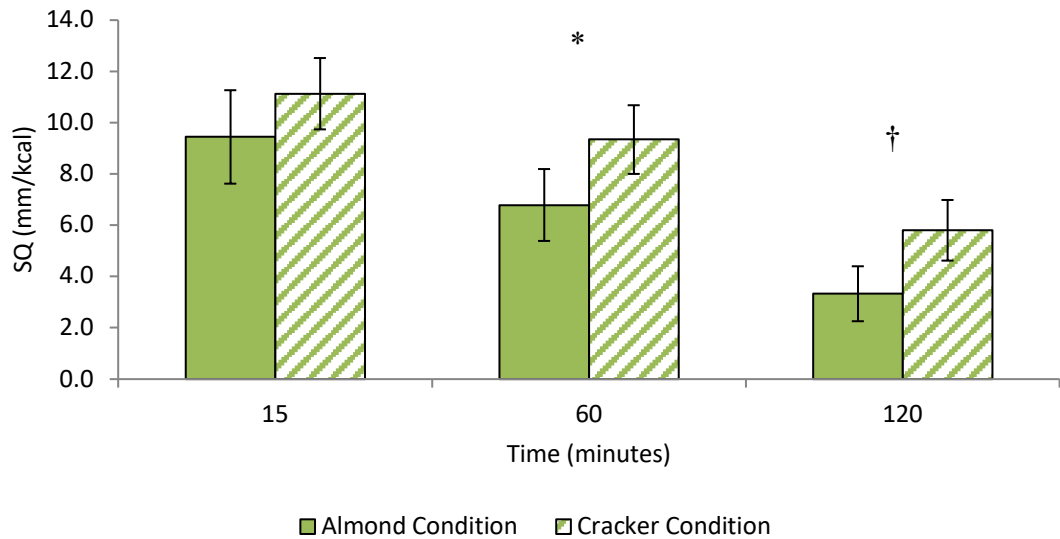
(b)
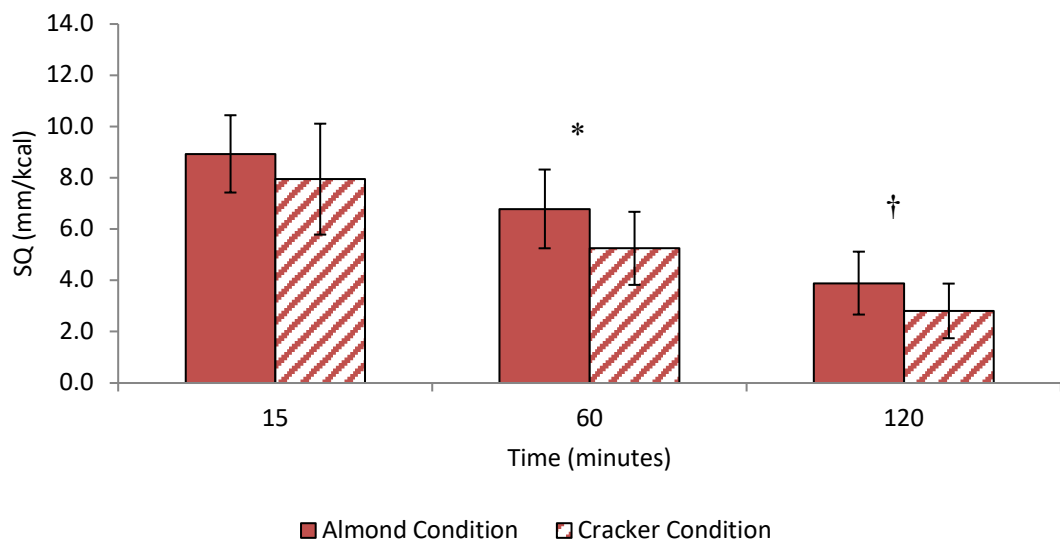
Figure 7.9. SQ for Hunger for the 120 minute period post consumption for the high (a) and the low (b) satiety phenotype. Note: *HSP vs. LSP $p<0.05$; †HSP vs. LSP $p = 0.07$.

7.4.8   Perceptions of Mid-Morning Snack

The mid-morning snacks were rated as equally palatable and habitual consumption of the different snack items did not differ ($p = .22$; $p = .14$, respectively). Almonds were perceived as healthier ($p<0.001$, $d = 2.8$) and more filling ($p<0.01$, $d = 0.8$) compared to

the crackers. In addition, almonds were rated higher with regards to aiding successful weight management ($p<0.001$, $d = 2.0$) and lower likelihood of overconsumption ($p<0.01$, $d = 0.9$). Immediately following the mid-morning snack desire to eat more of the snack was lower in the almond condition compared to the cracker condition ($p<0.05$, $d = 0.5$). Participants rated the almonds as more difficult to chew ($p<0.001$, $d = 1.1$) and felt the portion size was greater ($p<0.05$, $d = 0.6$) compared to the crackers. See Table 11 for the palatability and perception ratings of the mid-morning snacks.

Table 7.11. Mean (standard deviation) palatability and perception ratings.

	Almonds	Crackers	p value
How strong is your desire to eat more?	2.3 (2.2)	3.6 (2.4)	**p<0.05**
How difficult was it to consume the snack?	5.3 (2.5)	2.9 (2.0)	**p<0.001**
How suitable was the portion size?	7.6 (1.5)	6.7 (1.7)	**p<0.05**
How much more could you eat of the snack?	2.1 (1.7)	2.5 (1.7)	p = .22
How often do you consume this kind of snack?	3.2 (1.4)	2.6 (1.0)	p = .14
How pleasant was the taste of the snack?	4.6 (1.9)	5.2 (1.5)	p = .22
To what extent do you think the snack is healthy?	5.9 (1.1)	2.5 (1.3)	**p<0.001**
To what extent do you think the snack is high fat?	4.4 (2.0)	5.3 (1.2)	p = .06
To what extent do you think the snack is high calorie?	4.7 (2.0)	5.2 (1.5)	p = .25
How filling do you consider the snack to be?	5.3 (1.3)	4.2 (1.4)	**p<0.01**
To what extent do you associate this snack with successful weight management?	5.1 (1.4)	2.2 (1.5)	**p<0.001**
To what extent do you associate this snack with consuming too much?	3.1 (1.9)	4.8 (1.6)	**p<0.01**

7.5   Discussion

The present study examined individual differences in satiety responsiveness in normal weight and overweight women; then compared the effect of consuming different snack foods on measures of appetite including subjective appetite, energy intake and food reward, in individuals classified as low or high satiety phenotypes. Based on previous research, it was hypothesised that the low satiety phenotype, would be characterised by behavioural, psychological and physiological risk factors for overconsumption. In addition, it was hypothesised that different snack foods may modulate appetite and subsequent energy intake of the low satiety phenotype.

The current study found that under controlled laboratory conditions the satiety quotient is a reliable marker of satiating efficiency. The present study found that using the satiety quotient, it is possible to identify individuals who reliably experience weak satiating efficiency after a standardised test meal. Previous research has demonstrated the usefulness of individual appetite sensations to predict overall energy intake (Drapeau et al., 2005) and more recently the ability of the satiety quotient to not only predict individual energy intake, but to reliably measure satiety responsiveness to determine a low satiety phenotype (Drapeau et al., 2007; Drapeau et al., 2013; Dalton et al 2015). In the current study, correlation coefficients for SQ across the study visits ranged between 0.41 – 0.63. This provides additional support for the use of the satiety quotient as a measure of satiety responsiveness.

In addition, low responsiveness was associated with higher resting metabolic rate and greater energy intake, as well as lower scores on the TFEQ Flexible Restraint subscale, a lower baseline hunger and age. A distinct low satiety phenotype was identified. The low satiety phenotype reported greater levels of hunger, desire to eat and prospective consumption across the day. In addition, they consumed more energy and reported greater craving for sweet foods compared to the high satiety phenotype. Regardless of individual satiety efficiency, consuming a mid-morning snack resulted in a lower overall hunger drive and a supressed hedonic preference (implicit wanting) for consuming high fat foods. While participants consumed a greater total amount of calories in the cracker condition compared to the water condition, total energy intake did not differ significantly between the almond condition and the water condition. Almonds were perceived as healthier and more filling compared to the crackers and rated higher with regards to adding successful weight management. Finally, consumption of almonds had a greater satiating efficiency in the low satiety phenotype compared to the crackers, while consumption of the crackers had a greater satiating efficiency in the high satiety phenotype.

The current study found that low satiety responsiveness was associated with higher resting metabolic rate and greater energy intake, as well as lower scores on the TFEQ Flexible Restraint subscale and lower baseline hunger. In recent years the role of resting metabolic rate in energy balance and appetite control has been reviewed (Blundell et al., 2012a; Blundell et al 2012b; Weise et al., 2014) and it has been suggested that resting metabolic rate may be a functionally relevant biological signal for energy need and subsequently act as a driver of appetite control and food intake. With this in mind it may

be that the greater resting metabolic rate observed in the low satiety phenotype may reflect a greater biological drive to eat. However, it is important to note that the fixed energy breakfast served to participants was individually calibrated according to individual measured energy requirement and it is therefore reasonable to propose that the weak satiety response displayed by the low satiety phenotype was not merely a function of energy needs not being accounted for by a smaller provision of food energy.

The low satiety phenotype reported lower levels of baseline hunger, desire to eat and prospective consumption and greater levels of fullness. All participants in the current study were regular breakfast consumers, however this was assessed via self-report during the screening process and we were unable to account for differences in habitual breakfast size. Therefore, it is not possible to determine whether the low satiety phenotype were habitually small breakfast consumers which could account for a lower baseline hunger. Alternatively, it may be that after a period of fasting the low satiety phenotype are poor at detecting their appetite sensations, which is consistent with the findings of Barkeling and colleagues (2007). One other possible explanation for this may be the specific habitual eating pattern, i.e. timing of eating, of the low satiety phenotype. While not measured here, previous research has demonstrated that low satiety responsiveness is associated with greater night eating symptoms (Drapeau et al., 2013), this might help explain why the low satiety phenotype typically report lower baseline hunger. We found that the low satiety phenotype had lower TFEQ Flexible Restraint scores compared to the high satiety phenotype. Flexible Restraint is one component of Cognitive Restraint (Stunkard & Messick, 1985; Westenhoefer, Munch & Pudel 1994) characterised by a more graduated approach to eating, dieting and weight compared to Rigid Restraint. Flexible Restraint is associated with lower TFEQ Disinhibition, lower BMI, less frequent and less severe binge eating episodes, lower self-reported energy intake and a higher probability of successful weight loss during a weight reduction programme (Westenhoefer, Stunkard & Pudel 1999). While previous studies have found Disinhibition to be associated with weak satiety responsiveness (Cornier et al 2004; Finlayson et al., 2012; Dalton et al., 2015), this is the first to demonstrate a link between satiety responsiveness and the Cognitive Restraint subscale of the TFEQ. The low satiety phenotype reported greater levels of hunger, desire to eat and prospective consumption across the day and subsequently consumed more energy compared to the high satiety phenotype. Previous research has demonstrated that a low SQ in response to a standardised test meal is negatively associated with energy intake under both laboratory

and free living conditions (Drapeau et al., 2005; Drapeau et al., 2007). It is evident when comparing the hunger profiles that the low satiety phenotype are less hungry at the beginning of the day, however despite this they have a lower suppression of hunger following a standardised test meal. This distinct profile of hunger suggests that the consumption of food exerts a weaker suppression of hunger in the early postprandial period in the low satiety phenotype. Furthermore, it is interesting to see that hunger recovers faster in the low satiety phenotype in the late postprandial period compared to the high satiety phenotype. Finally, the low satiety phenotype reported greater craving for sweet foods. This finding suggests that the low satiety phenotype may also be characterised by hedonic risk factors for overconsumption, as the tendency to experience greater food cravings has been associated with greater BMI (White et al., 2002; Franken & Muris 2005). In addition, this finding is consistent with that of previous research which found that the low satiety phenotype reported experiencing lower control over their cravings (Dalton et al., 2015).

Considering the effects of food in the two satiety phenotypes we were able to demonstrate that consumption of almonds had a greater satiating efficiency in the low satiety phenotype compared to the crackers. Surprisingly, in contrast consumption of crackers had a greater satiating efficiency in the high satiety phenotype compared to the almonds. This suggests that the type of food ingested appears to be important in differentially effecting satiety responsiveness in certain individuals. In other words, there is a food/individual interaction in the generation of satiety. This should not be surprising, since there are now many examples in human appetite research indicating that 'one size does not fit all'. With this in mind, future research should focus of identifying food properties that normalise satiety responsiveness and subsequent food intake in the low satiety phenotype. That is, in those people who have a demonstrable weak inhibition of hunger immediately after eating.

Our findings suggest that participants perceived almonds as having a greater satiating potential with almonds being perceived as healthier, more filling, less associated with overeating and more favourable for weight management compared to the crackers. Research has demonstrated that expectations about the satiating effects of food play a role in satiety (Cassady et al., 2012; Brunstrom 2011). Participants also perceived almonds as more difficult to chew. However, this did not appear to be a reflection of the pleasantness of the snack as the almonds and comparator snack were rated as equally palatable, rather than due to the texture of the almonds. The texture and chewiness of

almonds may represent an additional mechanism behind their greater satiating capacity, with evidence suggesting that oral processing plays an important role in food intake by affecting both satiation and satiety (Hogenkamp & Schioth 2013).

In this study there are some limitations to be considered. The method used to characterise the high and the low satiety phenotypes, resulted in a small sample size and therefore the findings of the current study, in particular the novel findings, should be sought to be replicated in a larger sample. However, it is worth noting that a number of the findings of the current study are consistent with those of previous work, which strengthens confidence in their reliability. Another limitation of the current study is its cross sectional nature, which makes it difficult to infer specific causes behind low satiety responsiveness and the low satiety phenotype. Furthermore, the quasi-experimental design of the study meant that it was not possible to randomise participants to the low and high satiety phenotype groups and so allow for potential confounds for example age of participants. Finally, as the current study only examined satiety responsiveness in normal and overweight female participants, the findings may not be generalisable beyond this group.

In summary, the current study provides support for the use of the satiety quotient to identify individuals who reliably experience weak or strong satiety responses to food and that the low satiety phenotype are characterised by behavioural and psychological factors associated with risk for overconsumption. Furthermore, the substitution of specific snack foods with differing nutrient profiles may enhance the satiety responsiveness of the low satiety phenotype.

Chapter 8

Postprandial Appetite and Gut Hormone Responses in Overweight and Obese Individuals varying According to Satiety Responsiveness

8.1   Abstract

Background: Some individuals exhibit a weak satiety response to food and may be susceptible to overconsumption. Previous research has established that appetite related peptides play a role in short term appetite control. There may be a specific metabolic profile associated with satiety responsiveness and the so-called low satiety phenotype. The purpose of this study was to evaluate the reliability of the satiety quotient as a marker of satiety efficiency when measurements were repeated 12 weeks apart in overweight and obese individuals. This study also aimed to examine the relationships between ghrelin, glucagon-like peptide 1 (GLP-1), peptide YY (PYY), insulin and glucose with subjective ratings of appetite, energy intake and the satiety quotient and then to compare the postprandial gut hormone profiles in high and low satiety phenotypes.

Method: Thirty-two healthy overweight and obese females participated (age: 32.0±11.4 years; BMI: 28.2±2.8 kg/m²); and peptide data was available for twenty-six of these (age: 29.7± 9.3 years; BMI: 28.2±3.0 kg/m²). Plasma was collected before and periodically after a standardised fixed energy breakfast for 230 minutes, after which an ad libitum lunch was provided. Subjective appetite was assessed throughout the morning. Satiety responsiveness was determined using the satiety quotient.

Results: Mean satiety quotient showed good reliability when assessed over 12 weeks. Postprandial profiles of ghrelin, GLP-1, PYY and insulin were not associated with changes in subjective appetite ratings or energy intake at the ad libitum test meal. However, postprandial profiles of glucose were associated with changes in hunger, fullness and desire to eat, but not energy intake at the ad libitum test meal. Fasting levels of ghrelin, GLP-1, insulin and glucose were not associated with satiety responsiveness.

The LSP demonstrated lower levels of baseline PYY and lower change in postprandial glucose during early satiety compared to the high satiety phenotype.

Conclusion: People differ markedly yet reliably in the expression of post-prandial satiety, however in the present study these differences only appear to be encoded in changes in postprandial glucose and fasting PYY. Postprandial satiety is probably mediated by a complex interaction between physiological and psychological variables.

8.2   Introduction

Despite high interindividual variability in SQ, it seems intraindividual variability in SQ is low. Drapeau and colleagues have demonstrated good reproducibility of the SQ as a measure of satiety responsiveness, when measurements were repeated 2-4 weeks apart (Drapeau et al., 2013). Likewise, in a study conducted within our research unit in Leeds, a distinct low satiety phenotype was identified with good consistency across test days and in response to different caloric loads, over four weeks (Dalton et al., 2015). Taken together these findings suggest that the satiety quotient represents a stable individual marker for satiety efficiency that can be used to characterise the low satiety phenotype. However, while these studies provide support for the use of the satiety quotient as a method of assessing satiety responsiveness and subsequently identifying the low satiety phenotype, future research is needed to address the reliability and consistency of the measure over longer (i.e. more than 4 weeks) periods of time.

It is well established that numerous appetite related peptides play a role in short term appetite control (Cummings & Overduin, 2007) and it is therefore possible they could play a specific role in satiety. Satiety can be assessed using appetite related peptides, in addition to subjective appetite and energy intake (Blundell, de Graaf et al., 2010). For instance, circulating levels of appetite related peptides can be used to infer satiety (Gibbons et al., 2014). Appetite related peptides can be categorised as either 'tonic' or 'episodic'. Tonic appetite signals are representative of the body's energy store, while episodic appetite signals fluctuate throughout the day in response to consumption of food. The majority of research conducted to date has focused on three episodic appetite related peptides: ghrelin, glucagon-like peptide (GLP-1) and peptide YY (PYY). Ghrelin is thought to have opposing actions on appetite control to GLP-1 and PYY.

Ghrelin is the only known circulating orexigenic hormone, which has been shown to enhance appetite and increase food intake in humans, consequently it has been termed

the 'hunger hormone (Kojima & Kamgawa 2005). Ghrelin is produced primarily by the stomach and small intestine (Caminos et al., 2005). In contrast to the other appetite related peptides which will be discussed, circulating levels of ghrelin increase shortly before meals and are supressed in the postprandial state (Cummings et al., 2001). These marked pre-meal surges suggest that ghrelin is implicated in mealtime hunger and meal initiation. In humans both the intravenous infusion and subcutaneous injection of ghrelin has been shown to increase feelings of hunger and food intake (Wren et al 2001; Murphy and Bloom 2006). In addition, circulating levels of ghrelin decreases in response to overfeeding and increases in response to chronic negative energy balance (Tschop et al., 2001). Ghrelin can also be thought of as a tonic hormone as it corresponds with the body's level of adiposity. For instance one study demonstrated obese individuals to have lower acylated ghrelin compared to normal weight controls (Shiiya et al., 2002) which was an unexpected finding as lower levels of ghrelin should result in lower hunger levels and a lower drive to eat. However, this finding would suggest this does not occur in obese individuals and may indicate a lack of sensitivity to ghrelin which contributes to their impaired appetite control. Although obese individuals have lower fasting ghrelin levels, they show a similar response to infused ghrelin i.e. increased food intake, as normal weight individuals (Druce et al., 2005). In addition, whilst ghrelin levels in obese individuals are supressed after food, it is not to the same extent as that in normal weight individuals (Le Roux et al., 2005). This study measured ghrelin levels in response to different calorie loads and the dose dependent response was not as clear to see in the obese individuals. This suggests that poor appetite control, overconsumption and weight gain could be a result of a down regulation of gut peptide signalling, and that ghrelin signals are being overridden by other factors, for instance, hedonic control of appetite. In a study which monitored physiological concentrations of peptides in the blood of overweight and obese individuals, ghrelin was found to be significantly associated with changes in subjective ratings of hunger, which in turn correlated with objectively measured food intake (Gibbons et al., 2013).

In contrast, GLP-1 and PYY are both anorexigenic appetite related peptides, which work to supress appetite. GLP-1 is produced primarily by L cells in the distal small intestine and is released into circulation after a meal (Murphy and Bloom 2006). GLP-1 infusion has been shown to reduce hunger and food intake (Gutzwiller et al 1999; Naslund et al., 1999; Verdich et al 2001). GLP-1 is a potent incretin which stimulates insulin release, and peripheral administration of GLP-1 inhibits appetite (Drucker and Nauck 1999).

Studies have demonstrated reduced post-prandial GLP-1 release in obese patients which normalise with weight loss (Verdich et al 2001). However, these findings have not always been replicated (Feinle et al 2002). In a more recent study which monitored physiological concentrations of peptides in the blood of overweight/obese individuals, GLP-1 was found to be negatively associated with subjective ratings of hunger in the late satiety phase as well as with energy intake (Gibbons et al., 2013). PYY is a 36-amino acid produced mainly by distal-intestinal L cells (Hagan 2002). PYY is secreted postprandially; circulating levels rise in response to food consumption, in proportion to caloric load, and are reduced by fasting (Batterham et al., 2006). Studies have shown that peripheral administration of PYY in humans decreases food intake (Batterham et al., 2002; Degen et al., 2005; Sloth et al., 2007). Examination of postprandial levels of PYY in obese individuals has produced inconsistent results (Kim et al., 2005; Stock et al., 2005). Some studies report that obese individuals display lower fasting levels of PYY (Le Roux et al., 2006) yet others have demonstrated normal sensitivity to the anorectic effects of PYY (Batterham et al., 2002). More recent work shows that obese individuals have an attenuated meal stimulated PYY response across a range of caloric loads (Batterham et al., 2006).

While the relationship between ghrelin and hunger have been reported as being generally similar, this had typically been done by simply by showing the profiles of the two over time following food consumption (Cummings et al., 2004). This means that the relationships are not shown statistically. This is also the case for anorexigenic appetite related peptides. Whilst profiles of GLP-1 and PYY show patterns similar to fullness and/or satiety, studies rarely report the actual relationship between these measures. Gibbons and colleagues (2013) however, have since reported a significant association between ghrelin and changes in subjective ratings of hunger and a negative association between GLP-1 and ratings of hunger in the late satiety phase. One possible explanation for the lack of comparison in this way is the large individual variability in peptide levels (Cummings et al 2001), which makes doing so difficult. An alternative would be to consider the individual change within each person after food consumption, for instance to examine whether the extent of the suppression of ghrelin is linked to the extent of the suppression of hunger (Gibbons et al., 2013). This would be of particular interest in individuals identified using the satiety quotient as low satiety phenotype.

In addition to the peptides already discussed, glucose may play a role in satiety and the low satiety phenotype. The glucostatic theory originally devised by Mayer (1953; 1955)

proposed that changes in blood glucose concentrations are detected by glucoreceptors which modify hunger and energy intake accordingly. According to this theory an increase in blood glucose concentrations results in increased feelings of satiety, where as a drop in blood glucose concentrations has the opposite effect (Chaput & Tremblay, 2009). Furthermore, and in contrast to those already considered, insulin is a tonic appetite signal which means it is representative of the body's energy store. Insulin is produced by the pancreas and is a signal of adiposity stores in the body (Schwartz et al., 1992). Levels of insulin decrease during negative energy balance and increase during positive energy balance (Woods et al., 1974). Insulin levels are sensitive to food intake, they increase rapidly after food is consumed. Circulating levels are also dependent on individual sensitivity (Porte et al., 2002) for instance insulin sensitivity is reduced in proportion to body fat stores. Once insulin reaches the brain it acts as an anorexigenic hormone to supress appetite.

Existing studies such as these have provided a theoretical basis for a specific metabolic profile associated with satiety responsiveness and the low satiety phenotype. Previous research has sought to characterise the metabolic profile of the low satiety phenotype in response to a test meal (Drapeau et al., 2013). In this study, blood samples were taken before and at regular intervals following a standardised test meal, from low and high satiety phenotypes determined using the satiety quotient, in a group of obese males. Although the low satiety phenotype group did not reveal any specific fasting metabolic profile, they displayed a blunted cortisol response to the test meal compared to the high satiety phenotype. Poor meal induced cortisol has been acknowledged as an indicator of dysregulation of the hypothalamic-pituitary-adrenal (HPA) axis (Pruessner et al., 2003; Bjorntorp and Rosmond, 2000). Furthermore, previous research has shown that women with high waist circumference also demonstrate a blunted cortisol response to a meal (Garcia-Prieto et al., 2007). These results are consistent with those of other studies that have reported a positive association between awakening cortisol response (ACR) and SQ for fullness (Therrien et al., 2008). Whilst the study conducted by Drapeau and colleagues (2013) did not reveal a specific metabolic profile for the low satiety phenotype, the metabolic variables assessed were somewhat limited and the lack of associations with SQ may not mean that metabolic components are not associated with the low satiety phenotype. For instance, appetite related peptides, such as ghrelin, GLP-1, PYY, leptin, insulin and glucose could be implicated and remain to be explored.

8.2.1 Study Aims

There were three aims for the current study. The first was to establish whether weak satiety responsiveness, determined using the satiety quotient, can be characterised by behavioural, psychological or physiological risk factors for overconsumption in overweight and obese individuals. The second aim was to evaluate the reliability of the satiety quotient as a marker of satiety efficiency when measurements were repeated 12 weeks apart. The final aim was to explore the relationship between appetite related peptides and satiety responsiveness and determine whether there is a specific metabolic profile associated with satiety responsiveness and the low satiety phenotype.

8.3 Method

8.3.1 Participants

Participants were recruited via a University of Leeds email distribution list which staff, and students, as well as members of the public are able to sign up to. The recruitment email included some information about the study, the inclusion criteria and a screening questionnaire which consisted of questions concerning the exclusion criteria. Suitable individuals were invited to attend a screening session at the Human Appetite Research Unit. Thirty-six female participants were invited to take part in the study and of these thirty-two (age: 32.0±11.4; BMI: 28.2±2.8) were recruited to the study. All participants provided written informed consent and the study was granted NHS ethical approval.

8.3.2 Design

The study followed a repeated measures design. Each participant attended the Human Appetite Research Unit at the University of Leeds on five occasions: a screening and measures session, then four experimental sessions spread across twelve weeks. The study design is summarised schematically below (Figure 1). Each study session was scheduled at least seven days apart, Visit 4 and Visit 5 were conducted 12 weeks after Visit 2 and Visit 3, respectively. During these 12 weeks all participants took part in supervised exercise sessions at the Human Appetite Research Unit. For all visits, participants were required to refrain from eating or drinking anything besides water from 10pm the evening before to ensure a standardised fasting state and to abstain from drinking alcohol or engaging in physical activity for 24 hours prior to the session. Compliance with this instruction was assessed at the beginning of each session by self-report. During the

screening and measures session eligibility was confirmed. Height, weight, waist circumference, resting metabolic rate and body composition were measures. During the experimental sessions participants consumed breakfast, lunch and dinner at the research unit, participants were permitted to leave the unit in the period between lunch and dinner but were instructed not to eat or drink anything besides water. Compliance with this instruction was verified using an end of day questionnaire. Ratings of subjective appetite were taken at regular intervals throughout the test day using a validated hand-held Electronic Appetite Rating System (EARS-II); in addition blood sample measurements were performed to assess circulating levels of appetite related peptide (Insulin, Glucose, Ghrelin, GLP-1 and PYY) throughout the morning. The breakfast provided to participants was fixed and individually calibrated (proportional to 25% of participants measured resting metabolic rate); this enabled the satiety quotient to be calculated and satiety responsiveness to be determined for each participant. An ad libitum lunch and dinner test meal was used to assess energy intake.
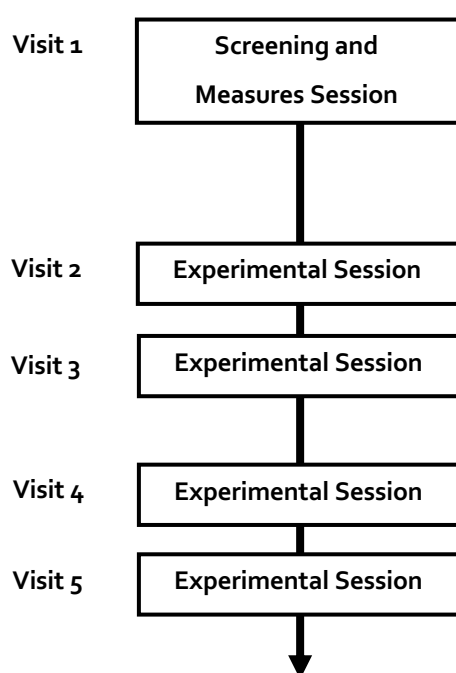
Figure 8.1. Schematic representation of study design.

8.3.3 Measures

8.3.3.1 Resting Metabolic Rate

Participants resting metabolic rate was assessed, during the measures session, using an indirect calorimeter fitted with a ventilated hood (GEM; Nutren Technology Ltd);

described in more detail in Chapter 3. RMR was used to calibrate the fixed energy breakfast served to participants; to provide 25% of their resting energy requirement.

8.3.3.2 Anthropometrics and Body Composition

Standing height without shoes was measured to the nearest 0.5cm using a stadiometer and body weight was measured to the nearest 0.1kg using an electronic balance. Waist circumference (cm) was measured at the participants naval after expiration. In order to obtain an estimate of participant's fat mass, fat free mass and percentage body fat air plethysmography (BodPod, Concord, CA, USA) was used. Anthropometric and body composition measures were conducted during the measures session according to standard operating procedures and are described in more detail in Chapter 3.

8.3.3.3 Eating Behaviour and Psychological Wellbeing Questionnaires

Participants completed the Three Factor Eating Questionnaire (TFEQ; Stunkard & Messick, 1985); Control of Eating Questionnaire (CoEQ; Hill et al., 1991) and Binge Eating Scale (BES; Gormally et al., 1982) during the measures session. These questionnaires were used to assess levels of restraint, disinhibition and hunger; mood, appetite and experience of food craving, as well as binge eating severity. Participants also completed the Beck Depression Inventory (BDI-II; Beck et al., 1996), Perceived Stress Scale (PSS; Cohen et al., 1983), State Trait Anxiety Inventory (STAI; Spielberger et al., 1998), during the measures session. These questionnaires are described in more detail in Chapter 3.

8.3.3.4 Subjective Appetite Sensations

Measures of hunger, fullness, desire to eat and prospective consumption were assessed using 100-mm VAS presented on an Electronic Appetite Rating System (EARS). These are described in greater detail in Chapter 3. Ratings were completed at baseline, before and after each event in the procedure and at hourly intervals throughout the day.

8.3.3.5 Appetite Related Peptides

Participants were fitted with a venous cannula upon arrival at the research unit and blood samples were taken at intervals before (-10, 0 minutes) and for three hours following breakfast (+10, +20, +30, +45, +90, +120, +180 minutes). Blood sample preparation and appetite peptide analysis are described in more detail in Chapter 3.

8.3.3.6 Energy Intake

The fixed energy breakfast served to participants comprised of muesli, raisins, sultanas and almonds combined with semi-skimmed milk. The macronutrient content of the breakfast was fixed at 55% carbohydrate, 30% fat and 15% protein (see Table 1 for details). Breakfast was individually calibrated to provide participants with 25% of their individual energy requirements. Participants were given 20 minutes to consume breakfast in its entirety. Ad libitum energy intake was assessed at both the lunch and dinner test meals. Participants were instructed to consume as much or as little as they wanted, but to eat until they reached a comfortable level of fullness. Food was weighed pre- and post-consumption to the nearest 0.1g to determine energy intake. The lunch test meal consisted of chili con carne with rice and strawberry yoghurt (see Table 2 for details) and was served four hours following breakfast. The dinner test meal consisted of tomato and herb risotto, salad items, garlic bread and chocolate brownies (see Table 3 for details) and was served four hours following lunch. Free-living ad libitum snack food intake was also assessed using a snack box which participants took away with them at the end of each experimental session (see Table 4 for details). Participants were informed that they could consume as much or as little as they wanted, but that they should not share, give away or dispose of them. Any uneaten food items, including the packaging, were returned to the research unit the following day.

Table 8.1. Nutritional information for the fixed energy breakfast.

Item	KCAL/100g	FAT/100g	CHO/100g	PRO/100g
Muesli Base	348.6	4.6	70.3	10.9
Raisins	268.6	0.0	69.3	2.1
Sultanas	274.7	0.4	69.4	2.7
Whole Raw Almonds	607.5	49.0	22.0	21.0
Semi-Skimmed Milk	50.0	1.1	4.8	3.6

Table 8.2. Serving size (g) and nutritional information for the lunch food items.

Item	Serving (g)	KCAL/ 100g	FAT/ 100g	CHO/ 100g	PRO/ 100g
Chilli Con Carne	650	130	5.0	13.0	7.0
Basmati Rice	245	153	1.6	30.9	3.3
Strawberry Yoghurt	425	106	3.8	13.2	4.7
Double Cream	45	439	47.5	1.5	1.5

Note: basmati rice mixed with chilli con carne; cream mixed with strawberry yoghurt.

Table 8.3. Serving size (g) and nutritional information of the dinner food items.

Item	Serving (g)	KCAL/ 100g	FAT/ 100g	CHO/ 100g	PRO/ 100g
Tomato & Herb Risotto	900	1611.0	36.9	287.1	33.3
Olive Oil	45	405.0	45.0	0.0	0.0
Garlic Bread	260	443.8	18.5	58.8	8.9
Lettuce	50	14.0	0.3	1.8	0.7
Cucumber	115	10.0	0.1	1.5	0.7
Tomatoes	115	20.0	0.5	3.1	0.7
Chocolate Brownies	140	437.0	20.4	56.1	6.0

Note: olive oil mixed into tomato and herb risotto.

Table 8.4. Serving size (g) and nutritional information for the snack box items.

Item	Serving	KCAL/ 100g	FAT/ 100g	CHO/ 100g	PRO/ 100g
Apple	1	46.8	0.1	11.8	0.4
Mandarin Orange	2	40.7	0.5	8.7	0.9
Ham	60g	119.7	2.8	1.4	22.3
Grated Cheese	75g	389.0	31.4	1.7	25.0
Wholemeal Bread	4 slices	212.1	2.2	40.4	10.2
Ready Salted Crisps	24g	126.4	8.0	12.9	1.5
Chocolate Buttons	50g	516.8	30.5	56.5	7.6
Vanilla Yoghurt	1 pot	46.6	0.1	7.5	4.4

8.3.3.7   Satiety Quotient

Hunger, Fullness, Desire to Eat and Prospective Consumption VAS ratings were used to calculate SQ for the 90-min period post breakfast. SQ for Hunger was then used to characterise participants as high or low in satiety responsiveness. The Satiety Quotient is described in greater detail in Chapter 3.

The following formula was used to calculate SQ:

$$SQ \ (mm/kcal) = \left(\frac{\text{rating before eating} - \text{mean of the 90-min post meal ratings}}{\text{energy content of the test meal (kcal)}} \right) \times 100$$

8.3.4 Procedure

For all sessions participants arrived at the research unit following an overnight fast. Participants were instructed not to consume alcohol or engage in physical activity for 24-hours and not to consume caffeine for 12-hours prior to the visits. During the initial screening and measures session eligibility was confirmed and participants provided written informed consent. Participants height, weight, waist circumference, resting metabolic rate and body composition were measured. Participants also completed a number of eating behaviour (TFEQ, CoEQ, BES) and psychological wellbeing (BDI, PSS, STAI, PoMS, WHOQoL) questionnaires. At the end of the session participants arranged to return a week later for the first experimental session. See Figure 2 below. On arrival participants were shown to a research cubicle where they completed the first set of VAS ratings. ELMA cream was applied to the site where the cannula was to be inserted and after 15 minutes the research team inserted the cannula and took the first blood sample. Participants returned to the cubicle and completed the second set of VAS ratings, breakfast was then served. Participants were given 20 minutes to consume breakfast in its entirety before completing another set of VAS ratings. Blood samples and VAS ratings were then taken at the following intervals +5, +30, +60, +90, +120, +180 and +230 minutes. During this time participants stayed in the research unit. At 235 minutes post breakfast the cannula was removed. The ad libitum lunch was then served. Following lunch participants completed another set of VAS ratings. Participants were then free to leave the research unit, returning four hours later for dinner. While away from the research unit participants completed VAS ratings at hourly intervals. At the end of the dinner session participants completed a VAS rating and were given a snack box to take away. See Figure 3 below. On completion of all study procedures participants received a written and verbal debrief and were compensated for taking part.
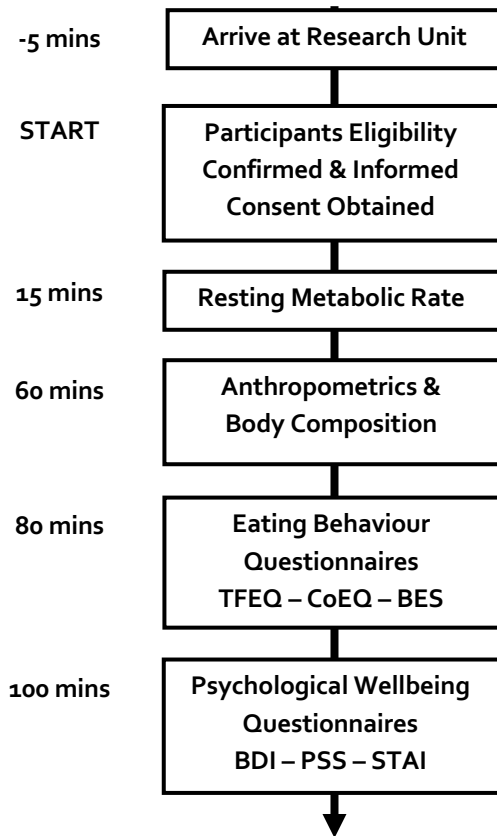
Figure 8.2. Schematic representation of screening and measures session (Visit 1).

Note: TFEQ; Three Factor Eating Questionnaire. CoEQ; Control of Eating Questionnaire. BES; Binge Eating Scale. BDI; Beck Depression Inventory. PSS; Perceived Stress Scale. STAI, State/Trait Anxiety Inventory.
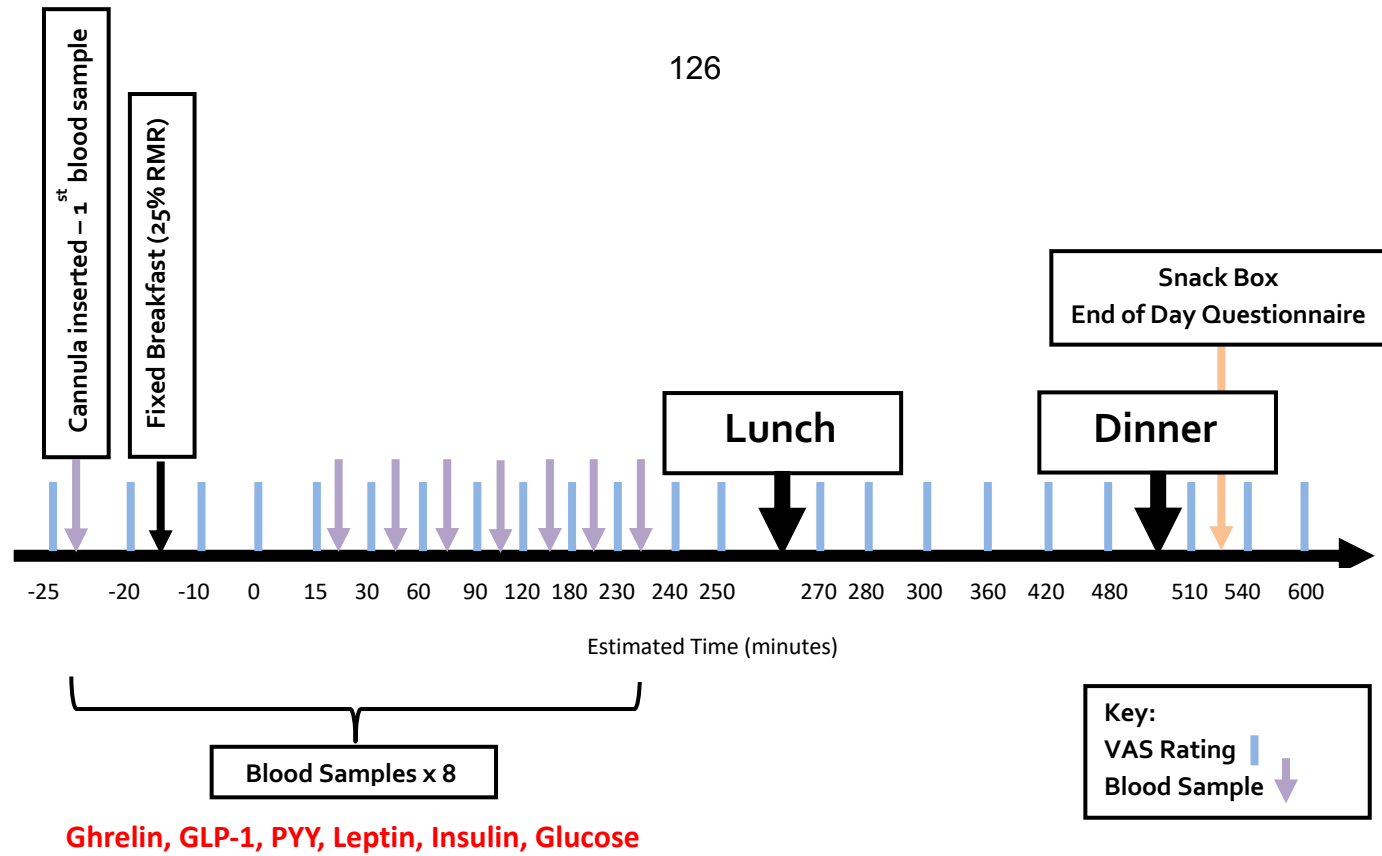
Figure 8.3. Schematic representation of experimental session (Visit 2-5)

8.3.5 Data Analysis

Data were analysed using Statistical Programme for Social Sciences Version 22. Reliability of the SQ was assessed by comparing SQ across experimental sessions, using Paired Samples t-tests, and by determining agreement between measures, using Pearson correlation coefficients. Pearson correlation coefficients were used to assess the relationship between physiological, psychological and behavioural variables and the SQ. Participants were then characterised according to individual satiating efficiency using average SQ for the 90-minute period following breakfast and a tertile split to identify high and low cut off points. Independent t-tests were used to compare scores on baseline measures (psychological, physiological, behavioural and metabolic) for the high and low satiety phenotype. To assess the effect of satiety responsiveness on subjective appetite sensations 2x22 Mixed ANOVAs were conducted, with time as the within subjects factor and satiety phenotype as the between subjects factor. Independent t-tests were used to examine the effect of satiety responsiveness on ad libitum energy intake. Due to large individual variations in fasting levels of appetite related peptides, change from baseline was calculated at each time point for each individual for all of the appetite related peptide variables. The postprandial period was separated into early (0-60 mins) and late (60-230 mins) (see Gibbons et al., 2013). Pearson correlation coefficients were used to assess the relationship between appetite related peptides, subjective appetite and ad libitum energy intake. Pearson correlation coefficients were also used to assess the relationship between behavioural (SQ) and physiological (fasting peptide levels) variables. Independent t-tests were used to assess the relationship between appetite related peptides in the high and the low satiety phenotypes. Finally, to assess the relationship between appetite related peptides and subjective appetite in the low and the high satiety phenotype paired samples t-tests were used. Where appropriate Greenhouse-Geisser probability levels were used to adjust for non-sphericity. Where significant effects were obtained post hoc analyses, with a Bonferroni correction for multiple comparisons were conducted. An α-level of .05 was used to determine significance; Cohen's d was used to measure effect size.

8.4 Results

8.4.1 Participant Characteristics

Table 8.5. Mean (SD) and range age, anthropometrics and body composition.

	Mean (SD)	Range
Age	32.0 (11.4)	19 – 55
Weight (kg)	77.0 (9.6)	63.1 – 112.4
Waist (cm)	28.2 (2.8)	25.0 – 35.5
Fat Mass (kg)	30.8 (7.5)	19.6 – 58.0
Fat Free Mass (kg)	46.2 (4.0)	39.8 – 55.0
Body Fat (%)	39.6 (5.1)	29.9 – 51.6

8.4.2 Reliability of the SQ as a Measure of Satiety Responsiveness

Table 8.6. Reliability of Satiety Quotient as a Measure of Satiety Responsiveness.

	Mean Difference (±SD)	Paired t-test p value	Correlation Coefficient
SQ Hunger	0.64 (5.2)	.49	.44*
SQ Fullness	0.63 (6.3)	.57	.15
SQ Desire to Eat	0.81 (5.2)	.39	.42*
SQ Prospective Consumption	1.22 (4.1)	.11	.54**
Mean SQ	2.45 (2.3)	p<0.001	.45*

Note: SQ at Visit 1 and Visit 2, separated by one week; *p<0.05; **p<0.01.

Table 8.7. Reliability of Satiety Quotient as a Measure of Satiety Responsiveness cont.

	Mean Difference (±SD)	Paired t-test p value	Correlation Coefficient
SQ Hunger	0.44 (4.0)	.60	.59**
SQ Fullness	0.23 (4.2)	.79	.39
SQ Desire to Eat	0.02 (3.9)	.98	.59**
SQ Prospective Consumption	0.10 (3.2)	.88	.58**
Mean SQ	1.23 (2.0)	p<0.01	.56**

Note: SQ at Week 1 and Week 12; **p<0.01.

8.4.3 Categorisation and Characterisation of Satiety Phenotypes

To categorise participants according to individual satiating efficiency, satiety quotient for the 90-minute period following breakfast was calculated and an average across visits was determined. A tertile split was then used to calculate high and low cut off points. Individuals with a mean SQ ≤ 6.5were classified as having a low appetite response to a meal i.e. the low satiety phenotype. Those with a SQ ≥ 11.1 were classified as the high

satiety phenotype. Ten participants were not categorised, these were not included in any subsequent analysis but for interest their characteristics are shown alongside the high and low satiety phenotypes in Table 8. As expected the low satiety phenotype had a significantly lower average SQ across study visits compared to the high satiety phenotype [t (20) = 11.57, p<0.001, d=5.2]. In addition, the low satiety phenotype reported lower levels of baseline hunger [t (13.2) = 5.77, p<0.001, d=2.6] desire to eat [t (20) = 4.79, p<0.001, d=2.1] and prospective consumption [t (20) = 2.22, p<0.05, d=0.9] and greater levels of baseline fullness [t (20) = 2.62, p<0.05, d=1.2].

Table 8.8. Mean (SD) SQ, appetite sensations, age, anthropometrics, body composition, RMR and eating behaviour traits for the high and the low satiety phenotype.

	HSP (n, 11)	LSP (n, 11)	Other (n, 10)
SQ (mm/kcal)[1]	12.6 (1.8)***	3.5 (1.9)***	8.9 (0.9)
Hunger[2]	67.4 (7.3)***	33.5 (18.1)***	51.0 (14.2)
Fullness[2]	19.1 (8.2)*	32.6 (14.9)*	27.9 (19.6)
Desire to Eat[2]	69.0 (11.5)***	38.8 (17.5)***	51.1 (20.6)
Prospective Consumption[2]	59.9 (13.8)*	43.9 (19.6)*	35.8 (17.3)
Age	30.5 (10.7)	31.8 (11.2)	33.9 (13.0)
Weight (kg)	75.1 (13.3)	77.8 (5.5)	78.2 (9.1)
BMI (kg/m²)	27.4 (3.1)	28.7 (2.5)	28.6 (2.9)
Waist (kg)	92.1 (10.0)	94.2 (8.9)	98.4 (8.9)
Fat Mass (kg)	30.2 (9.9)	30.3 (5.4)	32.0 (7.1)
Fat Free Mass (kg)	44.9 (4.2)	47.5 (3.0)	46.2 (4.5)
Body Fat (%)	39.5 (5.3)	38.7 (4.9)	40.6 (5.4)
RMR (kcal)	1641.1 (256.0)	1657.8 (189.8)	1635 (143.8)
TFEQ Restraint	6.9 (3.2)	9.3 (3.8)	8.4 (4.5)
TFEQ Disinhibition	9.2 (3.8)	8.6 (3.1)	9.7 (2.6)
TFEQ Hunger	6.6 (3.6)	5.6 (3.2)	7.3 (3.4)
Binge Eating Score	14.0 (9.8)	14.1 (8.6)	15.9 (5.2)

Note: [1]Average SQ; [2]Average Baseline Rating; *p<0.05; ***p<0.001.

8.4.4   Satiety Responsiveness and Psychological Wellbeing

There were no differences between the low and the high satiety phenotype on the Beck Depression Inventory or Perceived Stress Scale. However, on the Anxiety Inventory the low satiety phenotype scored higher for State Anxiety (p<0.05) compared to the high satiety phenotype.

Table 8.9. Psychological wellbeing scores for the high and the low satiety phenotype.

	HSP (n, 11)	LSP (n, 11)	p value
Beck Depression Inventory	7.7 (4.3)	9.0 (7.4)	.633
Perceived Stress Scale	11.5 (6.2)	16.5 (7.3)	.113
Anxiety Inventory - State	30.4 (4.7)	40.4 (11.3)	p<0.05
Anxiety Inventory - Trait	36.6 (7.5)	40.6 (10.8)	.349

8.4.5 Satiety Responsiveness and Subjective Appetite Sensations

There was a main effect of time on ratings of hunger, desire to eat prospective consumption and fullness [$F_{(21, 420)} = 60.4$, $p<0.001$; $F_{(21, 420)} = 60.9$, $p<0.001$; $F_{(21, 420)} = 55.5$, $p<0.001$; $F_{(21, 420)} = 48.3$, $p<0.001$, respectively] across the test day. In addition, there was a significant interaction between time and satiety phenotype on ratings of hunger [$F_{(21, 420)} = 7.47$, $p<0.001$], desire to eat [$F_{(21, 420)} = 5.89$, $p<0.001$], prospective consumption [$F_{(21, 420)} = 2.89$, $p<0.001$] and fullness [$F_{(21, 4200} = 2.45$, $p<0.001$]. There was no main effect of satiety phenotype on ratings of hunger, desire to eat, prospective consumption and fullness [$F_{(1, 20)} = 1.03$, $p = .322$; $F_{(1, 20)} = 1.14$, $p = .298$; $F_{(1, 20)} = .019$, $p = .891$; $F_{(1, 20)} = .001$, $p = .981$, respectively]. However, post hoc analyses revealed that baseline ratings of hunger, desire to eat, prospective consumption and fullness did differ significantly between the high and the low satiety phenotype. The low satiety phenotype reported lower baseline hunger [$t_{(13.2)} = 5.77$, $p<0.001$, $d=2.6$]; desire to eat [$t_{(20)} = 4.79$, $p<0.001$, $d=2.1$] and prospective consumption [$t_{(20)} = 2.22$, $p<0.05$, $d=0.9$] and greater fullness [$t_{(20)} = 2.62$, $p<0.05$, $d=1.2$] compared to the high satiety phenotype.
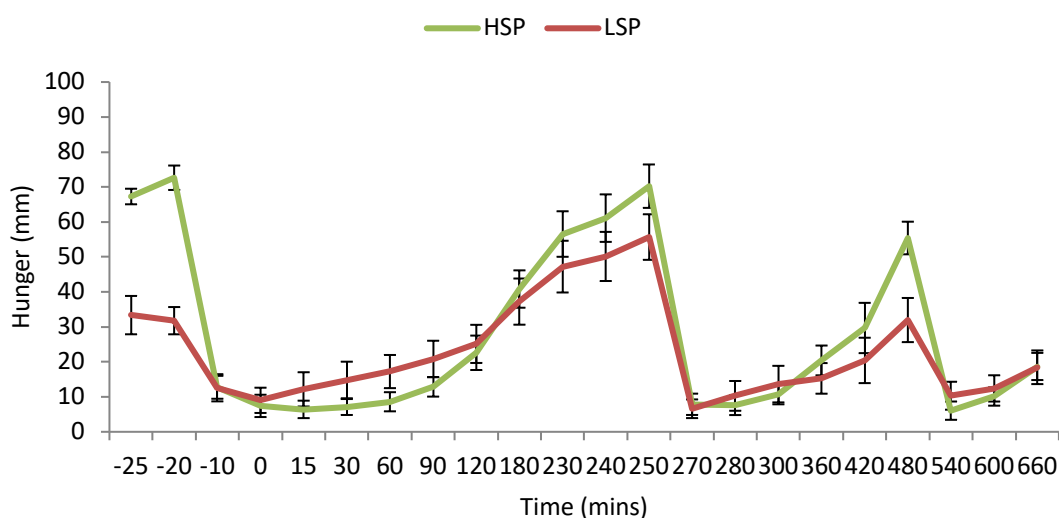
Figure 8.4. Ratings of hunger for the high and low satiety phenotype.
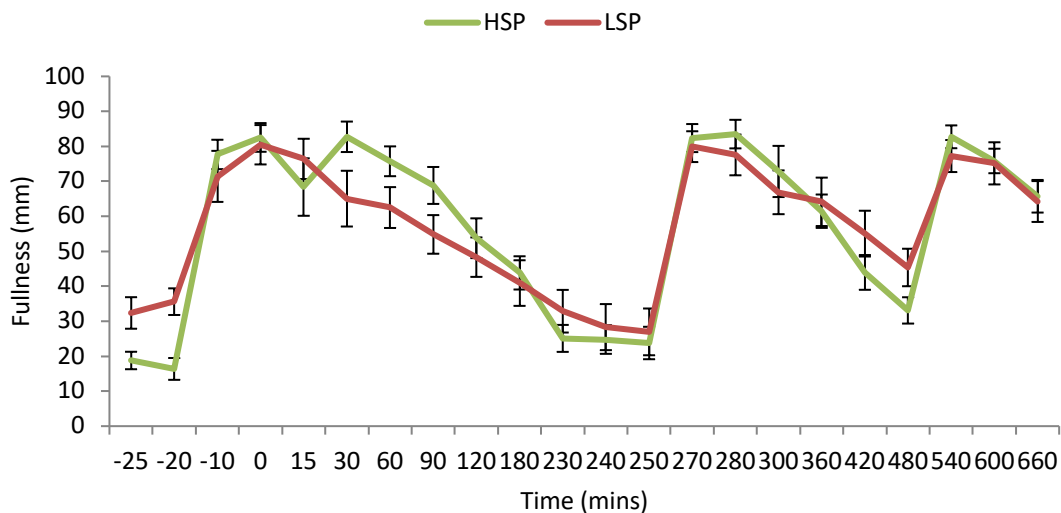
Figure 8.5. Ratings of hunger for the high and the low satiety phenotype.
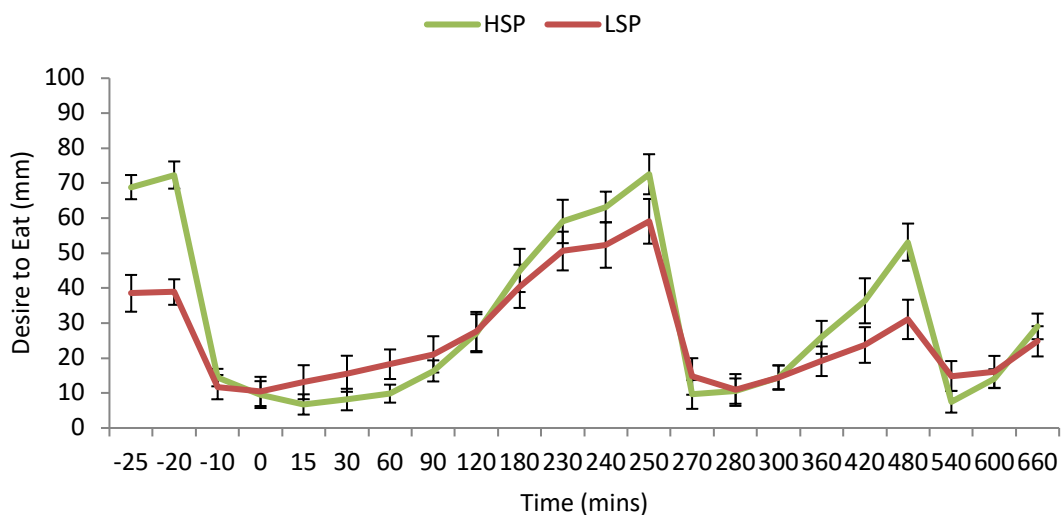
Figure 8.6. Rating of desire to eat for the high and the low satiety phenotype.
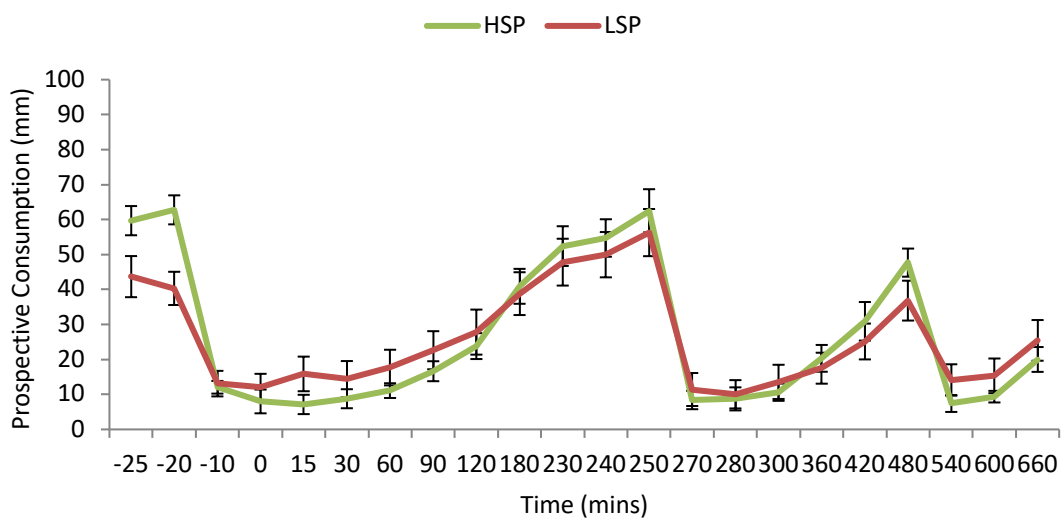
Figure 8.7. Ratings of prospective consumption for the high and low satiety phenotype.

8.4.6 Satiety Responsiveness and Energy Intake

There were no significant differences in energy intake at lunch, dinner or the snack box [t (20) = 0.85, p = .868; t (20) = 1.00, p = .328; t (20) = 0.96, p = .348, respectively] between the low and the high satiety phenotype. Overall energy intake did not differ significantly [t (20) = 0.13, p = .902] between the low and the high satiety phenotype.

8.4.7 Satiety Responsiveness and Appetite Related Peptides

Of the thirty-two participants who took part in the study, peptide data was available for twenty-six of these. See Table A (at the end of the Chapter) for participant characteristics.

Table 8.10. Absolute fasting levels of Ghrelin, GLP-1, PYY, Leptin, Insulin, Glucose and ratings of appetite for the overall sample and the high and the low satiety phenotype.

	Overall (n, 26)	HSP (n, 11)	LSP (n, 8)
Ghrelin	147.7 (94.9)	123.9 (59.9)	183.8 (143.0)
GLP-1	10.9 (5.4)	12.1 (6.2)	10.6 (5.8)
PYY	94.6 (33.1)	108.1 (38.3)*	74.1 (25.6)*
Leptin	52709.1 (23930.7)	50775.7 (21669.0)	54609.6 (24867.4)
Insulin	1031.2 (345.9)	1035.7 (396.5)	1089.4 (305.5)
Glucose	4.6 (0.39)	4.5 (0.44)	4.5 (0.26)
Hunger (mm)	55.4 (17.8)	70.1 (7.7)***	37.0 (14.3)***
Fullness (mm)	26.4 (14.4)	17.6 (7.9)***	36.1 (7.6)***

8.4.7.1 Appetite Related Peptides and Subjective Appetite

Associations between postprandial changes in ghrelin , GLP-1, PYY, leptin and insulin, and changes in ratings of hunger, fullness, desire to eat and prospective consumption were non-significant. There was a significant positive correlation between change in glucose and change in ratings of hunger during early satiety (r =.409, p<0.05). In addition, there was a significant negative correlation between changes in glucose and change in ratings of fullness (r =-.536, p<0.01) and a significant positive correlation between change in glucose and change in ratings of desire to eat (r =.402, p<0.05).

Table 8.11. Relationship (Pearson r) between postprandial changes in Ghrelin, GLP-1, PYY, Leptin, Insulin and Glucose and changes in subjective ratings of hunger.

	Mean (SD)	Overall	Early	Late
Ghrelin	-18.1 (32.6)	.137	.154	.034
GLP-1	9.7 (8.3)	-.020	-.173	.019
PYY	34.9 (34.9)	-.041	-.122	-.028
Leptin	-8932.3 (8004.2)	.114	-.047	.172
Insulin	2649.3 (1596.5)	.015	.001	-.080
Glucose	0.12 (0.67)	-.381	-.409*	-.150

Note: *p<0.05.

Table 8.12. Relationship (Pearson r) between postprandial changes in Ghrelin, GLP-1, PYY, Leptin, Insulin and Glucose and changes in subjective ratings of fullness.

	Mean (SD)	Overall	Early	Late
Ghrelin	-18.1 (32.6)	-.070	-.015	-.092
GLP-1	9.7 (8.3)	.231	.280	.196
PYY	34.9 (34.9)	.284	.312	.240
Leptin	-8932.3 (8004.2)	-.272	-.088	-.307
Insulin	2649.3 (1596.5)	.179	.130	.254
Glucose	0.12 (0.67)	.536**	.317	.348

Note: **p<0.01.

Table 8.13. Relationship (Pearson r) between postprandial changes in Ghrelin, GLP-1, PYY, Leptin, Insulin and Glucose and changes in subjective ratings of desire to eat.

	Mean (SD)	Overall	Early	Late
Ghrelin	-18.1 (32.6)	.045	.103	-.041
GLP-1	9.7 (8.3)	.072	-.028	.016
PYY	34.9 (34.9)	.236	.127	.212
Leptin	-8932.3 (8004.2)	.164	-.094	.276
Insulin	2649.3 (1596.5)	-.073	-.054	-.159
Glucose	0.12 (0.67)	-.402*	-.356	-.216

Note: *p<0.05.

Table 8.14. Relationship (Pearson r) between postprandial changes in Ghrelin, GLP-1, PYY, Leptin, Insulin and Glucose and subjective ratings of prospective consumption.

	Mean (SD)	Overall	Early	Late
Ghrelin	-18.1 (32.6)	-.106	-.039	-.126
GLP-1	9.7 (8.3)	-.058	-.118	-.108

PYY	34.9 (34.9)	.283	.127	.305
Leptin	-8932.3 (8004.2)	.242	.119	.261
Insulin	2649.3 (1596.5)	-.110	-.158	-.113
Glucose	0.12 (0.67)	-.261	-.347	-.078

8.4.7.2   Appetite Related Peptides and Ad Libitum Energy Intake

There were no significant associations between postprandial changes in any of the appetite related peptides and energy consumed from the ad libitum lunch (see Table 15)

Table 8.15. Relationship (Pearson r) between postprandial changes in Ghrelin, GLP-1, PYY, Leptin, Insulin, Glucose and energy consumed for the ad libitum lunch test meal.

	Mean (SD)	r	p value
Ghrelin	-18.1 (32.6)	-.009	.967
GLP-1	9.7 (8.3)	.376	.064
PYY	34.9 (34.9)	.016	.941
Leptin	-8932.3 (8004.2)	.259	.211
Insulin	2649.3 (1596.5)	.066	.754
Glucose	0.12 (0.67)	-.063	.759

8.4.7.3   Relationship between Behavioural and Metabolic Variables

There were no significant associations between any of the appetite related peptides in their fasting state, and satiety responsiveness (SQ for 90-minute period post breakfast).

Table 8.16. Relationship (Pearson r) between fasting metabolic variables and SQ.

	Mean (SD)	r	p value
Ghrelin	147.7 (94.9)	-.197	.345
GLP-1	10.9 (5.4)	-.032	.875
PYY	94.6 (33.0)	.309	.125
Leptin	52709.1 (23930.7)	-.140	.496
Insulin	1031.2 (345.9)	-.174	.395
Glucose	4.56 (0.39)	-.040	.848

8.4.7.4   Appetite Related Peptides in the High and the Low Satiety Phenotype

Table 17 shows baseline and postprandial change in appetite related peptide levels for the high and low satiety phenotype. The low satiety phenotype had lower baseline levels of PYY compared to the high satiety phenotype [t (17) = 2,17 p<0.05]. In addition, the

low satiety phenotype demonstrated lower change in postprandial glucose during early satiety compared to the high satiety phenotype [t (17) = 2.65, p<0.05].

Table 8.17. Mean (SD) baseline and postprandial changes in Ghrelin, GLP-1, PYY, Leptin, Insulin and Glucose for the high and the low satiety phenotype. Note: *p<0.05

		HSP (n, 11)	LSP (n, 8)
Ghrelin	Baseline	123.9 (59.9)	183.8 (143.0)
	Early Satiety	-51.6 (35.1)	-35.1 (46.9)
	Late Satiety	0.58 (39.8)	10.9 (30.9)
GLP-1	Baseline	12.1 (6.2)	10.6 (5.8)
	Early Satiety	16.3 (7.4)	16.6 (14.3)
	Late Satiety	7.9 (6.4)	4.3 (7.6)
PYY	Baseline	108.1 (38.3)*	74.0 (25.7)*
	Early Satiety	42.4 (44.9)	45.3 (33.9)
	Late Satiety	36.1 (40.7)	17.8 (19.1)
Leptin	Baseline	50775.7 (21669.0)	54609.6 (24867.4)
	Early Satiety	-7922.7 (7489.1)	-7893.9 (5273.3)
	Late Satiety	-10954.8 (8103.2)	-8442.5 (10337.6)
Insulin	Baseline	1035.7 (396.5)	1089.4 (305.5)
	Early Satiety	5590.9 (3077.8)	5843.9 (2468.7)
	Late Satiety	1057.8 (1321.6)	564.1 (469.9)
Glucose	Baseline	4.54 (0.44)	4.52 (0.26)
	Early Satiety	0.56 (0.61)*	0.19 (0.63)*
	Late Satiety	-0.38 (0.66)	-0.82 (0.80)

There was a main effect of time on the level of postprandial change in appetite related peptides including ghrelin, GLP-1, PYY, leptin, insulin and glucose [$F_{(6, 96)}$ = 16.1, p<0.001; $F_{(6, 102)}$ = 21.84, p<0.001; $F_{(6, 102)}$ = 9.96, p<0.001; $F_{(6, 102)}$ = 2.98, p<0.05; $F_{(6, 102)}$ = 67.6, p<0.001; $F_{(6, 102)}$ = 12.3, p<0.001, respectively]. There was also a main effect of satiety phenotype on postprandial level of glucose [$F_{(1, 17)}$ = 4.84, p<0.05]. Post hoc comparisons revealed that change in glucose was significantly greater in the high satiety phenotype compared to the low satiety phenotype at 60, 90 and 180 minutes (p<0.05). There was however no main effect of satiety phenotype on any of the other appetite related peptides, and there were no significant interactions.
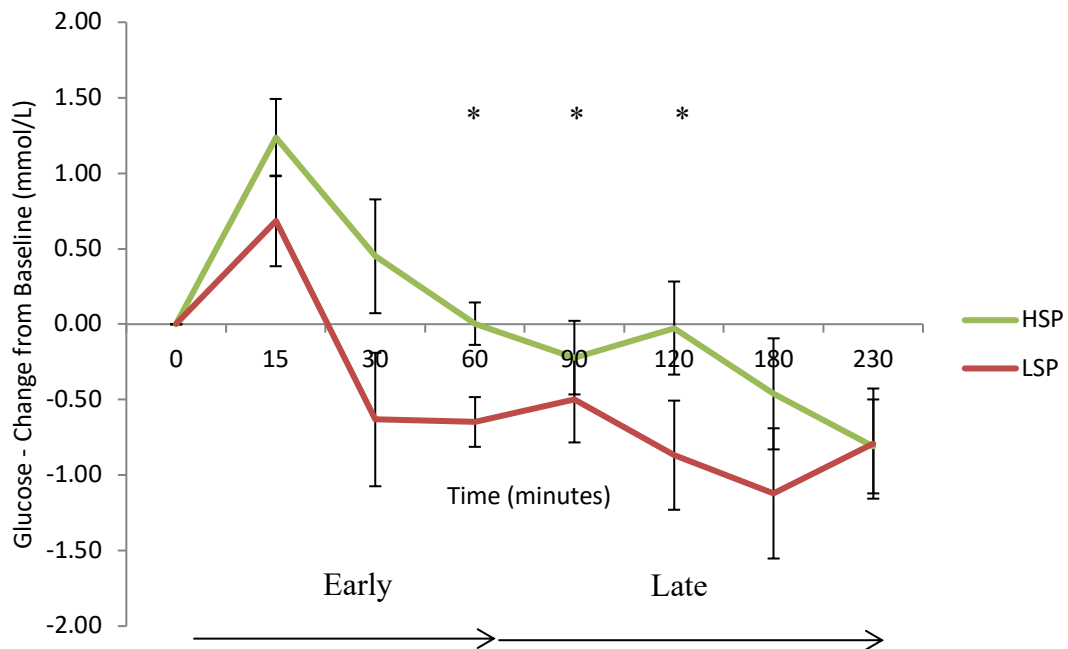
Figure 8.8. Postprandial profile of Glucose for the high and the low satiety phenotype.

8.5 Discussion

The first aim of the current study was to establish whether weak satiety responsiveness, determined using the satiety quotient, identified a distinct phenotype, characterised by behavioural, psychological and physiological risk factors for overconsumption in a sample of overweight and obese individuals. Secondly, it aimed to evaluate the reliability of the satiety quotient as a marker of satiety efficiency when measurements were repeated up to 12 weeks apart. Finally, the current study also aimed to explore the relationship between appetite related peptides and satiety responsiveness and determine whether there is a specific metabolic profile associated with satiety responsiveness and the low satiety phenotype. It was hypothesised that the low satiety phenotype, determined using the satiety quotient, would be characterised by behavioural, psychological and physiological risk factors for overconsumption. In addition, that the satiety quotient is a reliable measure of satiety responsiveness across study visits up to twelve weeks apart. Finally, that satiety responsiveness would be related to both fasting and postprandial appetite related peptides and more specifically that the low satiety phenotype would be characterised by a specific metabolic profile. The findings of the current study indicate that it is possible to identify individuals who reliably experience weak satiating efficiency after a standardised test meal using the satiety quotient, which is consistent with previous

findings presented in this thesis. In addition, that under controlled laboratory conditions the satiety quotient is a reliable marker of satiating efficiency. Which are consistent with previous findings presented in this thesis. Finally, this study was able to show that the low satiety phenotype is associated with some behavioural, psychological and metabolic factors. These included some novel associations as well as some which are consistent with previous findings from both within and outside of our research unit.

Previous research has demonstrated the usefulness of individual appetite sensations to predict overall energy intake (Drapeau et al., 2005) and more recently the ability of the satiety quotient to not only predict individual energy intake, but to reliably measure satiety responsiveness to determine a low satiety phenotype (Drapeau et al., 2007; Drapeau et al., 2013; Dalton et al., 2015). However, despite the support provided by these studies they are limited by the period of time over which measures were taken. As a result the current study aimed to evaluate the reliability and consistency of the satiety quotient as a marker of satiety efficiency when measurements were repeated up to 12 weeks apart; and we found that under controlled laboratory conditions and over 12 weeks, the satiety quotient is a reliable marker of satiating efficiency. In the current study, correlation coefficients for SQ across the 12 weeks ranged between .56 and .59. These correlations represent a moderate agreement between the measures of SQ (Portney & Watkins, 2000) and are also in line with those reported in previous studies.

The current study found that low satiety responsiveness was associated with lower levels of baseline hunger and higher levels of state anxiety. While we did not find that the low satiety phenotype reported greater levels of hunger, desire to eat and prospective consumption or lower levels of fullness across the test day; we did find that the low satiety phenotype reported lower levels of baseline hunger, desire to eat and prospective consumption and greater levels of fullness. All participants in the current study were regular breakfast consumers, however this was only assessed via self-report during the screening process and not actually measured. Therefore, it is not possible to determine whether the low satiety phenotype were habitually small breakfast consumers which could account for a lower baseline hunger. Alternatively, it may be that after a period of fasting the low satiety phenotype are particularly poor at detecting their appetite sensations, which is consistent with the findings of Barkeling and colleagues (2007). One other possible explanation for this may be the specific habitual eating pattern, i.e. timing of eating, of the low satiety phenotype. While not measured here, previous research has demonstrated that low satiety responsiveness is associated with greater night eating

symptoms (Drapeau et al., 2013), this might help explain why the low satiety phenotype typically report lower baseline hunger. In addition, the current study found that the low satiety phenotype scored higher for state anxiety compared to the high satiety phenotype. This finding is consistent with that of previous research which reported a negative correlation between satiety quotient and present state anxiety (Drapeau et al., 2013). These findings suggest anxiety may be involved in the satiety phenotype and may explain the vulnerability to overeat which has been demonstrated in previous studies (but not the present one). What is more, studies have consistently found positive associations between obesity and anxiety (Gariepy, Nitka & Schmitz, 2010). More specifically, a number of studies have demonstrated that state anxiety predicts increased food intake (Lau, Eley & Stevenson, 2006; Platte et al., 2013).

Furthermore, the current study did not find that low satiety responsiveness was associated with a higher BMI. This finding is consistent with previous studies who also report no associations between satiety responsiveness and BMI (Drapeau et al., 2013; Dalton et al., 2015). It has been suggested that weakened satiety responsiveness may become important for weight gain later in life (Dalton et al., 2015). This may be one explanation for the lack of association found between satiety responsiveness and BMI in the current study. Future research should look at satiety responsiveness in an older sample to investigate this. Contrary to previous research, the current study did not find low satiety responsiveness or low satiety phenotype to be associated with ad libitum energy intake

Previous research has reported that the low satiety phenotype are characterised by an attenuated cortisol response to a test meal (Drapeau et al., 2013); in this particular study this was the only meal induced metabolic change associated with lower satiety efficiency. The present study however measured a number of appetite related peptides. We found that postprandial profiles or ghrelin, GLP-1, PYY and insulin were not associated with changes in subjective appetite ratings or energy intake at the ad libitum test meal. However, postprandial profiles of glucose were associated with changes in hunger, fullness and desire to eat, but not energy intake at the ad libitum test meal. Furthermore, fasting levels of ghrelin, GLP-1, PYY, insulin and glucose were not associated with satiety responsiveness. Interestingly in the present study the low satiety phenotype demonstrated lower levels of baseline PYY and lower change in postprandial glucose during early satiety compared to the high satiety phenotype. PYY is an anorexigenic appetite related peptide which works to supress appetite, therefore in line with this we might expect that the low satiety phenotype would also demonstrate greater levels of

baseline hunger. We found that despite lower levels of baseline PYY the low satiety phenotype reported significantly lower levels of baseline hunger compared to the high satiety phenotype. One explanation for this could be that the low satiety phenotype are poor at detecting internal satiety signals. In addition, the low satiety phenotype had lower levels of postprandial glucose compared to the high satiety phenotype. According to the glucostatic theory of appetite control (Mayer 1953; Mayer 1955) an increase in blood glucose results in increased feelings of satiety where as a reduction has the opposite effect. In line with this blunted glucose response, the low satiety phenotype also typically demonstrate reduced feelings of satiety when assessed via subjective appetite sensations. It may be that the subjective appetite ratings (i.e. hunger, fullness, desire to eat and prospective consumption) experienced and reported by the satiety phenotypes are driven by their glucose response. Furthermore, previous research has reported that glucose area below fasting values was associated with weight gain (Boule et al., 2008). Our findings suggest that the low satiety phenotype experience higher glucose area below fasting glucose concentrations which may increase the risk of body weight gain in the LSP. What is more, previous research has reported that the low satiety phenotype are characterised by an attenuated cortisol response to a test meal (Drapeau et al., 2013). In this particular study, it was the only meal induced physiological change associated with lower satiety efficiency. It could be that a blunted glucose and cortisol response in the low satiety phenotype are linked. This would however require further research to investigate.

The current study carried some limitations, and these should be considered. The method used to characterise the high and the low satiety phenotypes, resulted in a small sample size and therefore the findings of the current study, in particular the novel findings, should be replicated in a larger sample. However, it is worth noting - that a number of the findings of the current study are consistent with that of previous work, this strengthens their reliability. Another limitation of the current study is its cross sectional nature, which makes it difficult to infer specific causes behind low satiety responsiveness and the low satiety phenotype. Finally, as the current study only examined satiety responsiveness in overweight and obese female participants, the findings may not be generalisable beyond this group.

Table A. Mean (SD) age, anthropometrics, body composition, RMR and eating behaviour traits for the overall sample and the high and the low satiety phenotype.

	Overall (n, 26)	HSP (n, 11)	LSP (n, 8)
Age	29.7 (9.3)	30.5 (10.7)	31.4 (9.1)
Weight (kg)	77.2 (10.3)	75.1 (13.3)	78.5 (6.0)
BMI (kg/m^2)	28.2 (3.0)	27.4 (3.1)	29.1 (2.7)
Waist (cm)	94.4 (9.2)	92.1 (10.0)	94.2 (8.1)
Fat Mass (kg)	30.7 (7.7)	30.2 (9.9)	30.6 (5.4)
Fat Free Mass (kg)	46.5 (4.1)	44.9 (4.2)	47.9 (3.1)
Body Fat (%)	39.3 (4.8)	39.5 (5.3)	38.8 (4.7)
TFEQ Restraint	7.9 (3.5)	6.9 (3.2)	8.3 (3.5)
TFEQ Disinhibition	8.8 (3.2)	9.2 (3.8)	8.3 (3.2)
TFEQ Hunger	6.4 (3.3)	6.5 (3.4)	6.1 (3.1)
Binge Eating Score	14.2 (8.5)	14.0 (9.8)	13.0 (14.3)

Note: ***$p < 0.001$

Chapter 9 General Discussion

9.1 Overview of Studies

The research presented in this thesis includes a series of experimental studies designed within a biopsychological framework to examine the role of satiety responsiveness in appetite control. This thesis aimed to determine the validity and reliability of the satiety quotient as a measure of satiety responsiveness and as a method to categorise individuals according to satiety efficiency. In addition, it aimed to establish whether weak satiety responsiveness, determined using the satiety quotient, identifies a distinct phenotype – the low satiety phenotype, which is characterised by behavioural, psychological, physiological and metabolic risk factors for overconsumption. A summary of the aims and main findings from each experimental chapters can be found below in Table 9.1

9.2 The Satiety Quotient as a Measure of Satiety Responsiveness

Each experimental study in the current thesis contributed towards the assessment of the reliability and validity of the satiety quotient (SQ) as a measure of satiety responsiveness. The reliability of the satiety quotient was assessed using Pearson correlation coefficients, between measures of SQ on different occasions. In addition, to assess the validity of the satiety quotient associations between SQ and measures of appetite control (e.g. subjective appetite, energy intake, eating behaviour traits, food craving and food reward) were assessed using Pearson correlation coefficients. For all studies in the current thesis, SQ for Hunger was used in the calculation of the satiety quotient. The first and the final study also calculated SQ for fullness, desire to eat and prospective consumption as well as a mean of the four ratings. In the current thesis the use of the satiety quotient to assesses satiety responsiveness and determine the low satiety phenotype has been explored in samples of males and females, as well as normal weight (Chapter 4, 6 and 7) and overweight and obese individuals (Chapter 8). In the first study, presented in Chapter 4, correlation coefficients for SQ for all appetite sensations, across the study visits, which were conducted a week apart ranged between r = 0.49 – 0.64 (Study 1a) and r = 0.59 – 0.70 (Study 1b). The second study, presented in Chapter 5, aimed to determine the extent to which the satiety quotient was a consistent measure of satiety responsiveness across

high and low fat test conditions. A significant correlation between the SQ for high fat and low fat test meals at lunch (r = 0.51) and dinner (r = 0.42) was found. This finding demonstrates that when used to measure satiety responsiveness, SQ remains consistent across macronutrient conditions. In the fourth study, presented in Chapter 7, participants SQ was assessed on three consecutive weeks. In this study correlation coefficients for SQ across the visits ranged between r = 0.41 – 0.63. The final study, presented in Chapter 8, aimed to evaluate the reliability and consistency of the satiety quotient as a marker of satiety efficiency when measurements were repeated up to twelve weeks apart. It was evident that under controlled laboratory conditions and over twelve weeks, the satiety quotient is a reliable marker of satiating efficiency. In this particular study, correlation coefficients across measures ranged between r = 0.56 – 0.59. The correlations reported here all represent a moderate agreement between the measures of SQ (Portney & Watkins, 2000). Furthermore, the correlations reported in this thesis were in line with those reported in previous studies. Drapeau and colleagues (2013) have previously demonstrated good reproducibility of the SQ (r = 0.5 – 0.7) in men when measures were repeated over 2-4 weeks. In addition, SQ for hunger has shown good reliability over 4 weeks and in response to different energy loads (Dalton et al., 2015). The findings presented in this thesis confirm that despite high *inter*individual variability, *intra*individual variability in SQ is low. The reliability and validity of the satiety quotient in multiple samples has been demonstrated. Taken together these findings suggest the SQ is a stable individual marker for satiety that can be used to identify satiety phenotypes.

9.3   Satiety Responsiveness and Energy Intake

The current thesis has provided additional support for the role of satiety responsiveness in appetite control, in particular that energy intake differs according to individual level of satiety responsiveness. A significant negative association between SQ and ad libitum energy intake in the first study, presented in Chapter 4 as well as in the fourth study, presented in Chapter 7, was apparent. These findings are consistent with previous research that has shown a low SQ in response to a standardised test meal is negatively associated with energy intake under laboratory and free living conditions (Drapeau et al., 2005; Drapeau et al., 2007). Furthermore, it was established, in the third and fourth study, that the low satiety phenotype consume more energy at ad libitum test meals, presented here in Chapter 6 and 7. The findings of the current thesis confirm that the low satiety phenotype reveals a tendency to eat more food, compared to the high satiety phenotype.

9.4   Satiety Responsiveness and Subjective Appetite

Based on the energy intake findings of the current thesis, it might have been expected that the low satiety phenotype would have higher levels of baseline hunger, desire to eat and prospective consumption. However, it has been established across multiple studies (Study 1 and Study 4,) that SQ is positively associated with baseline hunger. It was found that the low satiety phenotype reported lower levels of baseline hunger (Chapter 4, 6, 7 and 8), desire to eat (Chapter 6, 7 and 8) and prospective consumption (Chapter 6 and 8), as well as greater levels of baseline fullness (Chapter 6 and 8). One possible explanation for this may be that following a period of fasting the low satiety phenotype are particularly poor at detecting their appetite sensations. This notion is consistent with findings of previous work conducted by Barkeling et al (2005). In addition, it became apparent that the low satiety phenotype did not consistently report greater levels of hunger, desire to eat or prospective consumption or lower levels of fullness across the test day. While the low satiety phenotype did report greater levels of hunger, desire to eat and prospective consumption, alongside lower levels of fullness across the test day in Study 1(a) and Study 4. This was not the case for all experimental chapters. For instance, in Study 1(b) the low satiety phenotype only reported lower levels of fullness across the test day. Similarly, in Study 3 and 5 there was no effect of satiety phenotype on ratings of hunger, desire to eat, prospective consumption and fullness across the day.

9.5   Satiety Responsiveness and Eating Behaviour Traits

The studies in the current thesis have identified a number of associations between eating behaviour traits and the satiety quotient as well as differences between the high and the low satiety phenotype. Firstly, it was established that SQ was negatively associated with TFEQ Hunger and Disinhibition (Study 1(a) and Study 3, respectively). In addition to these associations, the low satiety phenotype displayed greater levels of TFEQ Hunger (Study 1a) and Disinhibition (Study 3) compared to the high satiety phenotype. These findings are consistent with existing research. For example, it has been proposed that high levels TFEQ external locus for hunger may indicate a poor awareness of internal physiological state. A trend towards a negative association between SQ and external hunger has previously been reported (Drapeau et al., 2013). What is more, this finding has since been replicated. In a more recent study by Drapeau and colleagues (2019) individuals identified as low satiety responders expressed higher levels of external locus

for hunger. Furthermore, TFEQ Disinhibition has been associated with overconsumption and weaker changes in appetite sensations in response to a fixed energy test meal in a previous study (Barkeling et al., 2007). Greater levels of disinhibition have been consistently associated with increased ad libitum energy intake (Chambers & Yeomans 2011; Ouwens et al., 2003) and increased tendency for weight gain (Carr et al., 2013; Finlayson et al., 2012). In addition, several studies have demonstrated that disinhibition is associated with weak satiety responsiveness (Finlayson et al., 2012; Cornier et al., 2004). These findings are consistent with the findings of the current thesis. A novel finding in the current thesis was the relationship between the satiety quotient and TFEQ Flexible Restraint. In Study 4, presented in Chapter 7, SQ was found to be positively associated with TFEQ Flexible Restraint, a component of Cognitive Restraint. Flexible Restraint is associated with lower TFEQ Disinhibition, lower BMI, less frequent and less severe binge eating episodes, lower self-reported energy intake and a higher probability of successful weight loss during a weight reduction programme (Westenhoefer, Stunkard & Pudel 1999). Taken together these findings suggest the low satiety phenotype are likely to display psychological traits which increase their susceptibility to overconsumption.

The findings of the study presented in Chapter 8 provide evidence that the low satiety phenotype display greater state anxiety compared to the high satiety phenotype. This finding is consistent with that of previous research which reported a negative correlation between the satiety quotient and present state anxiety (Drapeau et al., 2013). In addition, studies have consistently found positive associations between obesity and anxiety (Gariepy, Nitka & Schmitz, 2010) and a number of studies have demonstrated that state anxiety predicts increased food intake (Lau, Eley & Stevenson, 2006; Platte et al., 2013). It is plausible therefore to suggest that anxiety may be involved in the satiety phenotype and may help to explain the increased risk for overconsumption which has been demonstrated in some of the previous studies reported here (Study 1(a) and Study 4).

9.6 Satiety Responsiveness and Food Reward and Food Craving

The findings presented here are the first to suggest that the low satiety phenotype may be characterised by hedonic risk factors for overconsumption. To measure hedonic risk factors for overconsumption in the low satiety phenotype, the Leeds Food Preference Questionnaire (Finlayson, King & Blundell., 2008) as well as the Control of Eating Questionnaire (Hill, Weaver & Blundell., 1991; Dalton et al., 2017) was used. It was found in Study 3, presented in Chapter 6, that SQ was negatively associated with greater

implicit wanting fat bias. Furthermore, the low satiety phenotype consistently exhibited a greater wanting appeal bias for high fat foods compared to the high satiety phenotype. In other words, the low satiety phenotype chose high fat foods more frequently and faster than low fat foods. As previously discussed, research has shown that increased wanting for high fat foods is associated with a number of factors thought to increase risk of overconsumption. In contrast, the high satiety phenotype consistently exhibited a greater wanting appeal bias for low fat foods compared to the low satiety phenotype. This preference for low fat foods, may be protective against overeating and creating a positive energy balance. For instance, research has demonstrated that greater preference for low fat foods is negatively associated with energy intake under both laboratory and free living conditions (Dalton et al., 2013). Another difference between the low and the high satiety phenotype was found in Study 1(a), presented in Chapter 4. In this study, the low satiety phenotype displayed greater wanting for sweet foods compared to the high satiety phenotype. This preference for sweet foods in the low satiety phenotype is supported by the difference that was evident in Study 4. In Study 4, presented in Chapter 7, the low satiety phenotype reported greater craving for sweet food. The tendency to experience greater food cravings has been associated with greater BMI (White et al., 2002; Franken & Muris 2005). Finally, it was also found in Study 1(a) that the low satiety phenotype displayed lower control over cravings compared to the high satiety phenotype. The findings suggest that hedonic risk factors for overconsumption may be one of a number of factors that contribute towards impaired appetite control in the low satiety phenotype.

9.7   Satiety Responsiveness and Appetite Related Peptides

The final study, presented in Chapter 8, was the only study in the current thesis to compare the postprandial gut hormone profiles in high and low satiety phenotypes. The study aimed to explore the relationship between appetite related peptides and satiety responsiveness and determine whether there is a specific metabolic profile associated with satiety responsiveness and the low satiety phenotype. In this study, postprandial profiles of glucose were associated with changes in hunger, fullness and desire to eat. The low satiety phenotype demonstrated a lower change in postprandial glucose during early satiety compared to the high satiety phenotype. An increase in blood glucose results in increased feelings of satiety, while a reduction has the opposite effect (the glucostatic theory of appetite control – Mayer 1953; Mayer 1955). In line with this blunted glucose response, the low satiety phenotype typically demonstrate reduced feeling of satiety

when assessed by subjective appetite sensations, which may be driven by their glucose response. Previous research has reported that the low satiety phenotype are characterised by an attenuated cortisol response to a test meal (Drapeau et al., 2013). It could be that a blunted glucose and cortisol response in the low satiety phenotype are linked. In addition, in the final study in the current thesis the low satiety phenotype demonstrated lower levels of baseline PYY compared to the high satiety phenotype. As PYY is an anorexigenic appetite related peptide which works to suppress appetite, it might expected that the low satiety phenotype would also demonstrate greater levels of baseline hunger. However, despite lower levels of baseline PYY the low satiety phenotype reported lower levels of baseline hunger compared to the high satiety phenotype. Other studies in this thesis have also consistently demonstrated that the low satiety phenotype report lower levels of baseline hunger (Study 4, 6 and 7). One possible explanation for this could be that the low satiety phenotype are poor at detecting internal satiety signals. Alternatively, it could be proposed that the low satiety phenotype are showing a disconnect between physiological signals of satiety (appetite related peptides) and psychological sensations (subjective appetite). However, further work is necessary to probe the potential relationship between the satiety related peptides and the low satiety phenotype.

9.8   Satiety Responsiveness and Resting Metabolic Rate

A finding which was relatively consistent across the studies in the current thesis was the association between the satiety quotient and resting metabolic rate. It was found that SQ is negatively associated with resting metabolic rate in Study 1(b), Study 3 and Study 4. The role of resting metabolic rate in energy balance and appetite control has been reviewed in recent years (Blundell et al., 2012a; Blundell et al 2012b; Weise et al., 2014) and it has been suggested that resting metabolic rate may be a functionally relevant biological signal for energy need and subsequently act as a regulator of appetite control and food intake. It may therefore be that the greater resting metabolic rate observed in the low satiety phenotype reflects a greater biological drive to eat. However, it is important to note that the fixed energy breakfast served to participants in each study was individually calibrated according to individual measured energy requirement. It is therefore reasonable to propose that the weak satiety response displayed by the low satiety phenotype was not merely a function of energy needs not being accounted for.

9.9   Satiety Responsiveness and Body Weight/Composition

The research presented in the current thesis did not find that low satiety responsiveness was associated with a higher BMI. Furthermore, there were no differences in body weight or body composition between the high and the low satiety phenotype in any of the studies. While we might hypothesis that the low satiety phenotype is associated with greater body weight this does not appear to be the case. This could, to some extent, be a result of the study design. An alternative explanation for this could be that the low satiety phenotype is an intermediary phenotype between genetic susceptibility and overweight/obesity. Furthermore, it may be that weakened satiety responsiveness becomes more important for weight gain later in life, and the sample included in the current thesis were typically quite young. This is therefore something that should be investigated in future research.

9.10   The Low Satiety Phenotype

The research presented in this thesis has established that when measured using the satiety quotient, low satiety responsiveness is underpinned by a variety of risk factors for overconsumption. In addition, it has provided evidence that the low satiety phenotype appears to be a distinct behavioural phenotype that is characterised by behavioural, psychological and physiological factors associated with risk of overeating compared to the high satiety phenotype. As part of the current thesis the influence of different snack foods on appetite control in the low satiety phenotype was explored, presented here in Chapter 7. It was demonstrated that consumption of almonds, a snack food which is high in both protein and fibre, has a greater satiating efficiency in the low satiety phenotype compared to the high satiety phenotype. This suggests that the type of food ingested appears to be an important factor for the generation of satiety in certain individuals.

9.11   Implications: Treatment and Prevention

There are now many examples in human appetite research for a high level of individual variability, and the findings presented here provide additional support for this, indicating that 'one size does not fit all'. In addition, since the work on the current thesis was undertaken, there are examples of research exploring the effects of potential weight loss tools in the low satiety phenotype. For instance, Arguin and colleagues (2017) investigated the impact of a non-restrictive satiating diet in individuals displaying a high or low satiety phenotype. Furthermore, one study (Buckland et al., 2019) has demonstrated that women with a low satiety phenotype show greater resistance to weight

loss and another (Drapeau et al., 2019) that energy restricted weight loss intervention seems to trigger undesirable changes in some eating behaviour traits in the low satiety phenotype. These findings confirm the importance of individualised treatment and prevention interventions for the low satiety phenotype.

9.12   Methodological Issues

The findings presented in the current thesis alongside those reported in studies conducted by others suggest that the satiety quotient is a stable individual marker for satiety that can be used to assess satiety responsiveness and to characterise the low satiety phenotype. The satiety quotient can therefore be thought of as the gold-standard method for assessing satiety. Other methods of measuring satiety responsiveness have been suggested, for instance the Adult Eating Behaviour Questionnaire (Hunot et al., 2016). However, its use in research to date is limited and the validity of the AEBQ as a measure of satiety responsiveness remains to be tested against the SQ. The satiety quotient measures actual appetite sensations as well as actual consumption, both factors which underpin satiety. It would be fair to suggest that compared to the satiety quotient, items on the AEBQ which make up the factor of satiety responsiveness do not cover the construct sufficiently.

9.13   Limitations

One limitation of the experimental work conducted as part of the current thesis is that consideration was not given to the menstrual cycle where studies included female participants. In addition, the method used to categorise the high and the low satiety phenotypes throughout this thesis could be seen as a limitation as it resulted in a reduced sample size. Tertile splits were used which created a set of unclassified participants in each study that were not included in the data analyses. Another limitation to the current thesis is the cross sectional nature of the studies. This makes it difficult to infer specific causes behind low satiety responsiveness and the low satiety phenotype. Additionally, it is important to note the limitations of correlational tests. For example, a strong linear relationship between two variables is not synonymous with a strong agreement. To overcome this potential limitation level of agreement could instead be assessed. Furthermore, one criticism of previous studies, as well as those presented in the current thesis, focusing on satiety responsiveness and the low satiety phenotype is that habitual physical activity levels are not assessed. It is therefore not known whether the low satiety

phenotype are more or less physically active than the high satiety phenotype; a factor that could impact numerous elements of the satiety phenotype. Whilst the findings presented in the current thesis demonstrate that under laboratory conditions, SQ is a valid and reliable marker of satiety responsiveness. There are well known limitations to testing in laboratory conditions and whether the low satiety phenotype is valid and reproducible in the real life context remains to be explored. Also, it is worth noting that several of the differences that have been reported in the current thesis between the low and the high satiety phenotype are significant at the $p<0.05$ level. This means that the two groups are not categorically distinct and there will be overlap between the membership of the two types. Therefore, we should be cautious when drawing conclusions from the findings presented. Despite this limitation however, the phenotypes remain important because they tell us something about the high individual variability in the expression of appetite.

9.14   Future Directions

In the future there could be a focus on identifying food properties or interventions that normalise satiety responsiveness in the low satiety phenotype. There is a clear need to investigate how satiety can be strengthened either through functional foods or targeted interventions, which may be able to up regulate biological signals to prolong satiety. In addition, it is essential to discover whether low satiety responsiveness or a low satiety efficiency represents behavioural pathways through which genetic susceptibility to overconsumption and obesity affects body weight amount adults. It would be valuable in the future to examine associations between relevant gene variants and characteristics associated with low satiety responsiveness as well as determining whether a common underlying genotype can be identified for the low satiety phenotype. Furthermore, an important future direction based on this work would be to compile recommendations for the adequate assessment of the satiety quotient and the low satiety phenotype. For instance, additional analyses could be done to verify if there is a difference in the validity and reliability of the satiety quotient when using different post meal periods, or establish what is the most appropriate test meal to assess satiety quotient and the satiety phenotype.

Table 9.1 Summary of aims and main findings.

	Chapter 4 Study 1	Chapter 5 Study 2	Chapter 6 Study 3	Chapter 7 Study 4	Chapter 8 Study 5
Study Aim(s)	To determine the reliability and validity of the SQ To explore the characteristics of the low and high satiety phenotypes	To examine the effect of macronutrient manipulation (HF/LF) on the SQ To determine the extent to which SQ was consistent within individuals across HF/LF conditions	To confirm the validity of the SQ to categorise individuals as low or high satiety phenotypes To explore hedonic risk factors for overeating and obesity in the low satiety phenotype	To confirm the reliability and validity of the SQ in a female sample To compare the effect of consuming different energy-matched snack foods on appetite control in the low satiety phenotype	To evaluate the reliability of the SQ when measurements were repeated 12 weeks apart To examine the relationship between gut hormones and SQ, then to compare postprandial gut hormone profiles in high and low satiety phenotypes
Participant Characteristics	Males/Females Age: 27.7±11.1 years BMI: 24.9±3.1 kg/m²	Males/Females Age: 43.2±7.5 years BMI: 30.5±3.8 kg/m²	Females Age: 28.0±10.6 years BMI: 23.1±3.0 kg/m²	Females Age: 25.6±7.9 years BMI: 22.0±2.0 kg/m²	Females Age: 32.0±11.4 years BMI: 28.2±3.0 kg/m²

SQ	105-min post meal	Post Meal	75-min post meal	75-min post meal	90-min post meal
Reliability of SQ	*Study 1a* Hunger r = 0.63 Fullness r = 0.64 Desire to Eat r = 0.63 Pro Con r = 0.58 Mean AS r = 0.49 *Study 1b* Hunger r = 0.61 Fullness r = 0.71 Desire to Eat r = 0.68 Pro Con r = 0.59 Mean AS r = 0.70	HF/LF Lunch r = 0.51 SQ HF/LF Dinner r = 0.42	-	Visit 1 & Visit 2 r = 0.63 Visit 2 & Visit 3 r = 0.50 Visit 1 & Visit 3 r = 0.41	One Week Hunger r = 0.44 Desire to Eat r = 0.42 Pro Con r = 0.54 Mean AS r = 0.45 Twelve Weeks Hunger r = 0.59 Desire to Eat r = 0.59 Pro Con r = 0.58 Mean AS r = 0.56
Energy Intake	*Study 1a* SQ -ve associated with ad libitum energy intake	Total energy intake - ↑ high fat compared to low fat days	No significant association	SQ -ve associated with energy intake	No significant association

Subjective Appetite	*Study 1a & Study 1b* SQ +ve associated with baseline Hunger	No effect of HF/LF manipulation on hunger ratings	No significant associations	SQ +ve associated with baseline Hunger	No significant associations
Eating Behaviour Traits	*Study 1a* SQ -ve associated with TFEQ Hunger	-	SQ -ve associated with TEFQ Disinhibition	SQ +ve associated with TEFQ Flexible Restraint	No significant associations
Food Craving & Food Reward	No significant associations	-	SQ -ve associated with greater implicit wanting fat bias	No significant associations	No significant associations
Other	*Study 1b* SQ -ve associated with RMR SQ +ve associated with Age	Significant effect of HF/LF macronutrient manipulation on SQ at Breakfast, Lunch and Dinner	SQ -ve associated with RMR	SQ -ve associated with RMR SQ +ve associated with Age	-
Categorisation LSP	SQ Hunger Tertile Split	-	SQ Hunger Tertile Split	SQ Hunger Tertile Split	SQ Hunger Tertile Split

Characterisation LSP	*Study 1a*	-	LSP ↓ baseline Hun, Des, Pro and ↑ Ful	LSP ↓ baseline Hun and Des	LSP ↓ baseline Hun, Des, Pro and ↑ Ful
	LSP ↓ baseline Hun		LSP ↑ TFEQ Disinhibition	LSP = younger	LSP ↑ State Anxiety
	LSP ↑ Hun, Des, Pro and ↓ Ful Ratings		LSP ↑ Energy Intake	LSP ↑ Hun, Des, Pro and ↓ Ful Ratings	
	LSP ↑ TFEQ Hunger		LSP ↑ wanting for high fat foods	LSP ↑ Energy Intake	LSP ↓ baseline levels of PYY
	LSP ↑ wanting for sweet foods			LSP ↑ craving for sweet foods	LSP ↓ change in postprandial glucose during early satiety
	LSP ↓ Craving Control			(24hr CoEQ)	
	Study 1b				
	LSP ↓ baseline Hun, Des, Pro and ↑ Ful			Consuming almonds as a mid-morning snack had a greater satiating efficiency, compared to crackers in the low satiety phenotype	
	LSP ↓ Ful Ratings				
	LSP = younger				

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