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**The influence of anticipated meal timings on portion size decisions  
and interactions between meal timings, BMI, and delay discounting**

Annie Zimmerman

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School of Psychological Sciences

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## **Abstract**

Obesity is a global epidemic. Understanding drivers of food intake is critical to developing successful interventions. However, the current literature has neglected to consider the interaction between meal planning and future thinking in portion size decisions. For the first time, this thesis explores how anticipated meal timings influence portion selection. Novel methods manipulated the length and certainty of an inter-meal interval (IMI) and measured computerised and real portion size selection. Findings showed that information about the length of an IMI influences portion size decisions, and that individuals with a high BMI are less sensitive to information about the length and certainty of an IMI.

There is poor understanding of how future-orientated thinking influences decision making in this context. The studies compared performance on previously unrelated tasks; portion size selection in response to IMIs and monetary delay discounting. Results suggest that monetary discounting is associated with portion selection in response to uncertain, but not certain IMIs. An experiment assessing the effects of fasting on monetary and dietary discounting found that hunger had opposing effects on discounting of food and money; increasing dietary and decreasing monetary delay discounting. The thesis concludes that delay discounting is commodity specific, and therefore monetary tasks are not an adequate proxy for future-orientated eating behaviours.

The thesis also evaluated guidelines that regular meal timings promote weight loss. In studies assessing the relationship between BMI and chaotic eating (eating at irregular timings) no relationship was found, thus failing to support dietary recommendations. The thesis highlights that future thinking about meal timings effects portion size and is related to BMI. Nevertheless, current understanding of how future meal planning interacts with portion size, delay discounting and BMI is limited. Further research is necessary to establish how these separate aspects interact to promote, or protect against, obesity.

## **Dedication**

This thesis is dedicated to my partner in crime, James Wheale. Understory has provided me with a creative outlet that has kept me sane over the last three years. I have learnt so much from you about how to think innovatively, how to be a nonconformist, how to work in high-pressure situations with tight deadlines, and how to laugh my head off while making chocolate. Understory, and your friendship, has been the antidote to the loneliness that coexists with a Ph.D. I would not have started this Ph.D. or made it through without you. James, I think of you as a brother and I am so proud of the work we do together.

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## **Author declaration**

I declare that the work in this dissertation was carried out in accordance with the requirements of the University's Regulations and Code of Practice for Research Degree Programmes and that it has not been submitted for any other academic award. Except where indicated by specific reference in the text, the work is the candidate's own work. Work done in collaboration with, or with the assistance of, others, is indicated as such. Any views expressed in the dissertation are those of the author.

SIGNED: ..... DATE:.....

## Publications

**Zimmerman, A. R.**, Ferriday, D., Davies, S. R., Martin, A. A., Rogers, P. J., Mason, A., & Brunstrom, J. M. (2017). "What time is my next meal?" Delay-discounting individuals choose smaller portions under conditions of uncertainty. *Appetite*, 116, 284-290.

**Zimmerman, A. R.**, Mason, A., Rogers, P. J., & Brunstrom, J. M. (2017). Obese and overweight individuals are less sensitive to information about meal times in portion size judgements. *International Journal of Obesity*, 42, 905-910.

**Zimmerman, A. R.**, Johnson, L., & Brunstrom, J. M. (2018). Assessing "chaotic eating" using self-report and the UK Adult National Diet and Nutrition Survey: No association between BMI and variability in meal or snack timings. *Physiology & Behavior*, 192, 64-71.

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# 1 Chapter 1: Introduction

In this thesis the effects of anticipated meal timings on portion size decisions will be explored. The importance of meal timings has been recognised by public health policies, though little is understood about the extent to which planned meal timings influence eating behaviours or contribute to weight gain. A range of experiments are presented that were designed to test how information about the length and certainty of the inter-meal interval (IMI; time between two meals), influences portion size selection (computerised and real food intake) in participants with a wide-ranging body mass index (BMI). An additional aim of the thesis is to explore how delay discounting (a facet of impulsivity reflecting future orientation), manifests in dietary decisions that require individuals to think about future meals. The studies in this thesis comprehensively explore relationships between future meal planning, delay discounting and BMI.

Initially, this chapter will give an overview of the current understanding of obesity and energy balance. Subsequently, the two key topics central to the thesis will be presented, and the gaps in the current literature that form the basis of the research questions will be discussed. In the first half of the chapter, the literature on eating patterns will be presented, which touches on research questions 1, 2 and 3. This will be followed by a brief discussion of drivers of portion size and food intake, as well as how these issues relate to the central research question about meal timings as a determinant of portion size. The second half will introduce the field of impulsivity, future orientation and delay discounting, and explain how these currently unrelated topics could be connected. The thesis statement at the end of this chapter will outline the broad aims and objectives of the thesis.

## 1.1 *Overview of obesity*

An escalating global epidemic of obesity – “globesity” (WHO, 2013) – has become one of the most challenging public health issues in the UK and worldwide. Obesity and overweight are defined as abnormal or excessive fat accumulation that may impair health (WHO,

2016) and is typically measured using BMI (weight/height<sup>2</sup>). Obesity is defined as a BMI > 30 (WHO, 2018). The worldwide prevalence of obesity has increased dramatically, with rates having almost tripled since 1975 (WHO, 2018). Worldwide, 39% of adults aged 18 years and over (39% of men and 40% of women) are overweight (WHO, 2018). The UK has the highest rates of obesity in Western Europe, with one in every four (27%) adults in England being obese (Indicators, 2015). This number is estimated to increase to 60% of men and 50% of women by 2050 (Butland et al., 2007).

Obesity is a complex condition that spans all age and socioeconomic groups. There are serious physical, social and psychological ramifications; being overweight or obese increases the risk of type 2 diabetes, colon cancer, hypertension, hyperlipidemia, stroke, certain cancers, sleep apnea, liver and gall bladder disease, osteoarthritis, high blood pressure, musculoskeletal disorder, stroke and heart disease (Guh et al., 2009). There is also evidence that being obese can lower quality of life and self-esteem (Hatzenbuehler, Keyes, & Hasin, 2009), and is associated with mental health problems, such as depression and anxiety (Garipey, Nitka, & Schmitz, 2010; Luppino et al., 2010). Unsurprisingly, the healthcare costs associated with obesity are rising. In total, it is predicted that the cost of obesity to society is approximately £27 billion, though this number is expected to increase to £49.9 billion per year, with the cost to the NHS alone predicted to reach £9.7 billion (England, 2017).

The aetiology of obesity is complex, involving interacting genetic, evolutionary, social, psychological and environmental factors (Hruby et al., 2016). Establishing a detailed and nuanced understanding of the variables that contribute to the development and maintenance of obesity has proved to be challenging. Although there is much debate surrounding the drivers of obesity (Bleich, Ku, & Wang, 2011; James, 2008), there is consensus that positive energy balance is the root cause (Jequier & Tappy, 1999). Rudimentarily, weight gain is thought to be the result of a continuous imbalance between consumption and expenditure of energy (Anderson et al., 2015; Hill, Wyatt, & Peters, 2012).

The body is in energy balance, and weight should remain constant, if energy intake matches energy expenditure, (Hill & Commerford, 1996). When intake is higher than expenditure, energy balance becomes positive, leading to an increase in body mass (Hill & Commerford, 1996; Hill et al., 2012). Hence, food intake is arguably one of the most critical determinants of weight and obesity (Pearcey & de Castro, 2002; Stunkard, Berkowitz, Stallings, & Schoeller, 1999), reflected in the pattern of eating and overall energy intake. Indeed, it is argued that weight gain in the USA can be mostly explained by eating excess calories (Swinburn, Sacks, & Ravussin, 2009). Thus, in the interest of reducing obesity, it is critical to understand factors that increase food intake, which may consequentially affect energy balance and body weight. The central aim of the thesis is to explore how anticipated future meal timings may influence food intake. The subsequent section will present the literature on eating patterns, focusing on our current understanding of how eating patterns and irregular meal timings affect food intake, BMI and obesity.

## 1.2 *Eating Patterns*

Day-to-day habitual patterns of food intake are thought to play an important role in determining long-term energy balance, and researchers have taken an interest in specific 'eating patterns' that might promote obesity (Ma et al., 2003). 'Eating pattern' is an umbrella term, referring to people's habitual eating behaviours at mealtimes (e.g. example, breakfast, lunch or dinner) or snacking behaviour (Leech, Worsley, Timperio, & McNaughton, 2015). Various aspects of eating patterns have been studied in detail, including behaviours (e.g. frequency, timing, regularity, skipping); food type (e.g. macronutrient content, food pairings) and environment, (e.g. social eating, family context, restaurant or home setting; (Leech et al., 2015). Specific focus has been given to the effects of temporal characteristics of eating patterns (timing, frequency and regularity of eating occasions) on food intake, and implications for health and body weight (Almoosawi, Vingeliene, Karagounis, & Pot, 2016; Leech, Timperio, Livingstone, Worsley, & McNaughton, 2017; Mesas, Munoz-Pareja, Lopez-



Garcia, & Rodriguez-Artalejo, 2012). A key aim of this thesis is to examine how temporal eating patterns influence dietary decisions and BMI.

Most techniques used to measure eating patterns require participants to self-report their eating behaviours (Shim, Oh, & Kim, 2014; Walker, Ardouin, & Burrows, 2017); ranging from 24-hour recalls, where participants report all eating occasions within a 24-hour period; longer-term diet diaries, in which participants record all intake events during a set period (typically 7 days); and food frequency questionnaires, where participants are required to report on the frequency and types of food they consume (Perez Rodrigo, Aranceta, Salvador, & Varela-Moreiras, 2015). A more detailed evaluation of these methods is provided in Chapter 7, in which both a self-reported questionnaire and 7-day weighted diet diary are used to assess temporal patterns of consumption.

Eating occasions are typically classified as either a meal or snack. There is an extensive debate about how to define a meal vs. a snack in the literature, with great heterogeneity between definitions of meals and snacks (Berg & Forslund, 2015). Currently, various classification methods exist (Bellisle et al., 2003; Leech et al., 2015): quantitative definitions, where snacks and meals are discriminated based on objective criteria, such as the type of food (Lennernas & Andersson, 1999; Macdiarmid et al., 2009), the time of day (Almoosawi, Winter, Prynne, Hardy, & Stephen, 2012; Summerbell, Moody, Shanks, Stock, & Geissler, 1995), the length of the interval between one eating event and the next; and self-defined, where participants decide themselves if an eating occasion classifies as a snack or meal (Berteus Forslund, Lindroos, Sjostrom, & Lissner, 2002; Siega-Riz, Carson, & Popkin, 1998). These classification methods have disadvantages; the quantitative definitions involve arbitrary criteria that do not account for unusual meal patterns, and the self-reported classifications involve subjective interpretation of an individualised eating experience (Blake, Bisogni, Sobal, Devine, & Jastran, 2007). In Chapter 7, (c.f. Olea López & Johnson, 2016), meals and snacks are defined based on type of food, and also measures are used that

require participants to self-define these classifications. The subsequent sections will introduce specific elements of eating patterns.

### *1.2.1 Eating Frequency*

Eating frequency is a well-researched aspect of eating patterns. This is defined by the number of times an individual eats a snack or a meal, and is a critical aspect of meal patterning that has gained a lot of attention as a risk factor for weight gain and obesity (Colles, Dixon, & O'Brien, 2008; Kofman, Lent, & Swencionis, 2010; Leite, de Oliveira, Pereira, & Kiyomi, 2009; Saunders, 1999). The evidence as to whether eating frequency is associated with body size is mixed (Raynor, Goff, Poole, & Chen, 2015); paradoxically, both high and low eating frequency have been argued to contribute to weight gain and BMI. Some studies have reported inverse or null associations between eating frequency and BMI (Palmer, Capra, & Baines, 2009; Ruidavets, Bongard, Bataille, Gourdy, & Ferrieres, 2002) and obesity (Drummond, Crombie, Cursiter, & Kirk, 1998; Ma et al., 2003; Mills, Perry, & Reicks, 2011). These inverse relationships between eating frequency and BMI have been interpreted to mean that a 'grazing', or irregular, meal pattern is associated with leanness (Nicklas, Baranowski, Cullen, & Berenson, 2001). For example, it is argued that eating 'little and often' has metabolic advantages (Jenkins et al., 1989; McCrory, Nancy, Roberts, & Huang, 2018). Conversely, others have reported positive relationships between eating frequency and BMI (Howarth, Huang, Roberts, Lin, & McCrory, 2007; Leech, Worsley, Timperio, & McNaughton, 2018), which suggests that that eating frequency is a risk factor for obesity.

Despite evidence to support both conflicting interpretations, recent reviews have concluded that there is insufficient evidence to confirm any association between eating frequency and body weight (Canuto, da Silva Garcez, Kac, de Lira, & Olinto, 2017; Raynor et al., 2015). In addition, research into eating patterns has considered how irregularity in day-to-day eating frequency is related to BMI and associated health issues (see section

below). However, irregularity in eating patterns can reflect many different characteristics of eating, other than just variability in eating frequency.

### *1.2.2 Irregularity in eating patterns*

Traditionally, a Westernised meal pattern comprises three primary meals: breakfast, lunch and dinner. Recently, however, there has been an increase in unstructured eating - spontaneous snacking and eating meals at different times (Samuelson, 2000; Warde & Yates, 2016). This shift in eating habits is reflected in a decline in family mealtimes (Neumark-Sztainer, Wall, Fulkerson, & Larson, 2013) and a reduction in time spent preparing food at home (Zick & Stevens, 2010). Obesity-related eating behaviours are often described as 'nibbling', 'picking', 'grazing', 'between meal snacking', and 'unstructured' eating (Lane & Szabo, 2013). Similarly, research demonstrates that evenly spaced eating occasions are associated with better diet quality (Eicher-Miller, Khanna, Boushey, Gelfand, & Delp, 2016), and a 'grazing' temporal eating pattern is associated with poorer diet quality and BMI (Leech et al., 2017). Thus, it is critical to understand whether this shift away from structured meal timings has contributed to the rise in obesity rates, by exploring whether unstructured meal patterns promote eating behaviours linked to obesity.

Irregular eating is considered a risk factor for junk food consumption (Zahra, Ford, & Jodrell, 2014), weight gain (de Vos et al., 2015) and obesity (Ekmekcioglu & Touitou, 2010). However, although irregularity in eating behaviour has been researched extensively, there is little consistency in definitions of the term 'irregularity'. Research has assessed relationships between variable eating frequency (i.e. eating a different number of times each day) with BMI, energy intake and health. In these studies, irregularity has been defined as variability in the frequency of eating occasions from day-to-day. In randomised controlled trials and prospective studies, irregular eating frequency has been linked with increased energy intake (Farshchi, Taylor, & Macdonald, 2005b) and obesity-related health issues, such as metabolic syndrome (Sierra-Johnson et al., 2008; Wennberg, Gustafsson, Wennberg, & Hammarström, 2015), decreased thermic effect of food (Alhussain, Macdonald, & Taylor,

2016) and insulin sensitivity (Farshchi, Taylor, & Macdonald, 2005a). Other studies have assessed irregularity by simply asking participants to classify themselves as regular or irregular eaters, and found positive associations between irregularity with BMI (Kagamimori et al., 1999; Takahashi et al., 1999), metabolic syndrome and insulin resistance (Sierra-Johnson et al., 2008). One study assessed irregularity in day-to-day energy intake, and found a negative relationship between BMI and irregular energy intake (Pot, Hardy, & Stephen, 2014). Several studies have looked specifically at certain meals; irregularity in energy intake at breakfast has been associated with high BMI (Berkey, Rockett, Gillman, Field, & Colditz, 2003; Lehto et al., 2011; Rodrigues et al., 2016; Yang, Wang, Hsieh, & Chen, 2006).

Clearly there are various manifestations of irregularity in eating behaviour. Most of these studies focus on irregularity of eating frequency. However, no research has directly assessed the impact of irregularity in specific relation to the *timing* of meals, and how irregular meal timings link to obesity. Thus, little is understood about the specific effects of irregular or uncertain meal timings on eating behaviours or long-term weight change. The limited literature on meal timings will be reviewed in the subsequent section.

### 1.2.3 *Meal timings*

Meal and snack timings are determined by a complex interaction of socio-cultural (De Castro, 1997; de Castro, 2002), psychological, environmental and genetic factors (de Castro, 1999). The timing of eating occasions, specifically the distribution of caloric intake across the waking day (Garaulet & Gomez-Abellan, 2014), may have critical implications for energy balance and, consequentially, weight gain and obesity. Specifically, the timing of the evening meal is thought to play a role in weight gain; a recent review concluded that individuals who consume more calories in the evening are more likely to be overweight (Almoosawi et al., 2016). Observational studies reported that consuming more energy at dinner, compared to breakfast, was associated with high BMI (Kahleova, 2017), glucose control and insulin secretion (Morgan, Shi, Hampton, & Frost, 2012). Furthermore, the

temporal distribution of meals has been shown to affect the success of weight loss interventions. One study demonstrated that the timing of lunch predicted weight loss during a 20-week dietary intervention conducted in 420 obese and overweight individuals, and this effect was independent from the total caloric intake (Jakubowicz, Barnea, Wainstein, & Froy, 2013). A 12-week weight loss trial reported that high energy intake at breakfast led to greater weight loss than high energy intake at dinner (Garaulet et al., 2013). Similarly, two controlled studies found that later eating was associated with poor weight loss success in both a short-term 20-week weight loss trial (Arble, 2009) and a long-term follow up (6-year) after bariatric surgery (Ruiz-Lozano, 2016). However, although there is significant evidence that eating later in the evenings promotes weight gain, there are critical gaps in our understanding of how meal timings can influence health outcomes and BMI.

One key issue is that few studies have directly assessed irregularity in the *timing* of meals. There is observational evidence that shift workers, who eat at unusual, possibly irregular, hours, tend to have a higher risk of diabetes, cardiovascular disease (Esquirol et al., 2011; Wang et al., 2014) and obesity (Antunes, Levandovski, Dantas, Caumo, & Hidalgo, 2010; Peplonska, Bukowska, & Sobala, 2015). It is thought that eating at irregular and spontaneous circadian times may negatively impact metabolism as a possible pathway to obesity (Sun et al., 2018). The circadian rhythm is a biological process that follows a 24-hour oscillation and affects most human physiological processes and behaviours (Panda, Hogenesch, & Kay, 2002; Reppert & Weaver, 2002). Disruptions to circadian timings have been shown to have negative effect on human health, particularly in relation to obesity (Froy, 2010; Huang, Ramsey, Marcheva, & Bass, 2011). Indeed, more successful weight loss outcomes have been reported among obese women with a flatter and less fragmented pattern of their circadian rhythms (Bandin, Martinez-Nicolas, Ordovas, Madrid, & Garaulet, 2014). However, there are various factors involved with shift work that could contribute to weight gain and the development of obesity-related diseases, such as poor sleep, which limits the reliability of conclusions from these studies about how irregular meal timings

influences food intake and BMI. There are limited studies that have isolated irregularity in timings, hence future research is required to establish whether eating at irregular timings predicts high BMI.

Experiments in the current thesis investigate the effects of information about IMIs. While this is an under researched area, the typical IMI lengths of people in the US have been quantified. A meta-analysis of 40-year trends in eating behaviours spanning from 1971-2010 revealed that the average interval between all eating episodes, including snacks, ranged from 2.51 to 2.82 hours (Kant & Graubard, 2015). Within specific meals, the length of the IMI between breakfast and lunch ranged from 4.68-5.04 hours, and the IMI between lunch and dinner ranged from 5.9-6.55 hours. The intervals between meals and snacks were shorter, ranging from 2.69-3.04 hours between a mid-morning snack and lunch, and 3.31-3.75 hours between a mid-afternoon snack and dinner. Authors also reported that breakfast and lunch, but not dinner, timings were later in the more recent surveys, and interval between lunch and dinner increased over time, whereas the length of the IMI between breakfast and lunch remains unchanged. However, these results are limited to the US, and therefore are not generalisable to a UK, or global, population. Furthermore, there is limited information about IMIs and how they affect eating behaviour. Despite the lack of research about meal timings and IMIs, this area has become the focus of weight loss recommendations, which will be discussed in the following section.

#### *1.2.4 Guidelines for weight loss*

People with obesity who are attempting to lose weight, might consult government guidelines for healthy eating. In several countries, including the UK, Australia, and Canada, regular, structured meal timings are recommended for weight loss (Canada, 2017; Gov.au, 2012; NHS, 2017). Similarly, cognitive behavioural therapies for binge eating and obesity prescribe a regular, structured, meal pattern (Graham & Reynolds, 2013; Palavras et al., 2015). However, there is limited evidence to support these recommendations; a systematic review of eating patterns and obesity found no evidence to support the hypothesis that

irregular eating timings promotes weight gain (Mesas et al., 2012). In the past, government guidelines have received criticism for endorsing dietary advice that is not supported by empirical evidence (Gifford, 2002). Given the health, social and economic consequences of obesity, it is important to establish whether these recommendations are appropriate. To establish this, we must first understand the specific mechanisms by which irregular or uncertain meal timings might influence dietary decisions, and weight gain.

This thesis aims to challenge these recommendations in Chapter 5, by testing the hypothesis that individuals with a high BMI eat at irregular timings (Chapter 5). In addition, the effects of anticipated certain and uncertain meal timings on portion selection and BMI are explored in (Chapter 2, 3 and 4). In these studies, the effects of information about future meal timings. Understanding drivers of portion selection is essential for developing recommendations and interventions for weight loss. The follow section will present the research on portion size research, and evidence for relationships with BMI and obesity.

### *1.3 Portion size, BMI and obesity*

Given the limitations of the current literature on meal timings, the central aim of this thesis is to identify the extent to which future meal timings influence food intake. To unpick this research question, it important to outline the current understanding of drivers of portion size. This section will present an overview of research on the relationship between portion size and obesity and explain the role of pre-meal planning in portion size decisions, specifically focusing on expected satiety as a determinant of portion size.

In parallel to the rise in obesity, there has also been an increase in food portion sizes (Young & Nestle, 2002). This increase has been documented in both packaged commercial products and home-cooked foods (Wansink & Payne, 2009). The robust portion size effect shows that people eat more when served a larger portion (Benton, 2015; English, Lasschuijt, & Keller, 2015; Peter Herman, Polivy, Pliner, & Vartanian, 2015). A meta-analysis (Zlatevska, Dubelaar, & Holden, 2014) revealed that doubling a portion size leads to an approximate 35% increase in energy intake. This effect has been shown in both adults and

children, with a range of foods (Steenhuis & Poelman, 2017) and has been established in real-world settings (French et al., 2014).

It has been argued that this increase in portion size leads to an increase in total energy intake, which may be a contributing factor to the obesity epidemic (Steenhuis & Poelman, 2017). Empirical studies, while mostly supportive of this viewpoint, are limited. One study found that larger portion sizes lead to increased total intake in adults and five-year-old, but not three-year-old, children (Rolls, Engell, & Birch, 2000). Moreover, it has been shown that larger portions sizes generate an increase in energy intake that is sustained over several days (Rolls, Roe, Beach, & Kris-Etherton, 2005; Rolls, Roe, & Meengs, 2006a, 2007). Although several studies show that portion size influences energy intake, evidence for a causal relationship between portion size and BMI or obesity is scarce (Rolls, 2014). Studies supporting this link are mostly observational (Albar, Alwan, Evans, & Cade, 2014; Berg et al., 2009; Mesas et al., 2012), and should be interpreted with caution as they do not demonstrate causality (Ello-Martin, Ledikwe, & Rolls, 2005).

Weight loss interventions have begun to focus on reducing portion size, with mixed findings. In a weight loss intervention study, the use of portion control plates resulted in greater weight loss compared to self-selected diet (Rolls, 2014). However, it was not clear if it was the portion size or food consumption that led to the weight loss. In a four-week trial that increased the size of just the lunchtime meal, energy intake and weight increased, but these changes were not significant over time (Jeffery et al., 2007). A recent intervention focused on reducing portion size reported a decrease in BMI (Poelman et al., 2016), although others found that incorporating portion-control strategies in a one-year weight loss trial was not a helpful intervention to reduce body weight in the long-term (Rolls, Roe, James, & Sanchez, 2017). It has been argued that greater attention should be placed on ingestive frequency than portion size in weight management interventions (Mattes, 2014). While portion sizes have clearly increased over time and there is general consensus that this causes an increase in short-term energy intake, there is debate as to whether this has



contributed to long-term weight gain and obesity (Mattes, 2014). Nevertheless, as obesity is thought to stem from energy imbalance (Hill et al., 2012), higher energy intake than energy expenditure, a better understanding of the drivers of food intake and portion size is required to develop successful weight management strategies.

### *1.3.1 Pre-meal planning and expected satiety*

Recent research has attempted to understand drivers of portion size and food intake prior to consumption. In the past, studies seeking to understand decisions about portion size were focused on the termination of eating mid-meal (Blundell et al., 2010; Hetherington, 1996). It was believed that drivers of food intake or portion size can be understood by assessing events during the meal, such as fullness, that encourage meal termination. This premise is based on the notion that an individual will stop eating when they have reached an adequate level of fullness. However, it has become apparent that people decide how much to consume prior to the eating (Brunstrom, 2014). This research demonstrated that people evaluate the expected satiety of foods, and these subjective evaluations drive portion size selection. Consequentially, the focus of portion size research has shifted from exploring within-meal behaviours, to understanding the role of pre-meal planning in food intake.

Large observational studies have shown that the portion size of the meal is typically planned in advance— studies have shown that people tend to select a portion size and then clean their plate (Fay et al., 2011; Hinton et al., 2013; LeBow, Chipperfield, & Magnusson, 1985; Vermeer, Steenhuis, & Seidell, 2010; Wansink & Cheney, 2005; Wilkinson et al., 2012). Habitual plate clearing is shown to lead to the selection of larger portion sizes and increased energy intake (Wansink & Cheney, 2005). Furthermore, plate clearing has been shown to be predictive of heavier body weight (Robinson & Hardman, 2015). These studies have revealed that portion size selection requires a person to engage in pre-meal planning, and that the tendency to pre-plan in this way could promote weight gain. Therefore, it is important to focus on future meal planning to fully understand how portion size decisions are made.

To decide how much to eat, prior to eating, the characteristics of the food and meal must be assessed and considered. For instance, perceived pleasantness and the healthiness of the food have shown to influence food intake (Brogden & Almiron-Roig, 2010); portion size tends to increase the more a food is liked or perceived to be healthy (Faulkner et al., 2014). It is thought that foods perceived to be healthy typically have a lower energy density, so can be eaten in large quantities (Chandon & Wansink, 2007). Furthermore, selecting an appropriate portion size also requires an ability to be able to predict future effects of consuming different food portions. There is a trade-off between choosing a portion that is too small and being hungry during the IMI and choosing a portion that is too large and being over-full during the IMI. Indeed, portion size is often governed by the 'expected satiety' of a food. Expected satiety is defined as the extent to which foods are expected to stave off hunger (the desire to eat) between meals (Brunstrom & Rogers, 2009; Brunstrom & Shakeshaft, 2009). Expected satiety can be measured by presenting participants with an image of a food and asking them to select the amount they would need to eat to stave-off hunger. Typically, the Method of Adjustment task is used (Brunstrom, Shakeshaft, & Scott-Samuel, 2008), whereby participants are shown one fixed portion of food and one 'animated', adjustable portion of a different food. They are instructed to look at the fixed food and then alter the portion size of the animated food until they believe two foods would stave off hunger to the same extent. Using this method, expected satiety of food has shown to be an important predictor of portion size (Brunstrom & Rogers, 2009; Brunstrom & Shakeshaft, 2009).

Although it is now widely acknowledged that pre-meal expectations drive portion size selection, little is known about the effects of anticipated future meals timings on food intake. If, indeed, portion size decisions involve a trade-off between selecting too much food and being overly full during the IMI and selecting too little food and being overly hungry during the IMI, it is likely that knowledge about future meal timings, and therefore the length of an IMI, will have a significant impact on portion size decisions. This thesis aims to improve

understanding of how information about the length and certainty of the IMI influences portion size selection. In doing so, the research will address gaps in the existing literature about the inter-relationship between meal timings, weight gain and obesity.

This portion size research highlights that meal planning requires an individual to evaluate the future consequences or benefits of a decision. For example, when judging the expected satiety of a food in deciding how much to eat, an individual may be predicting how hungry or full they will be after having eaten that food. Thus, individuals appear to be making predictions about the future consequences before choosing how much to eat. However, it is widely accepted there are vast individual differences in the extent to which people consider the future when making decisions (Atance & O'Neill, 2001; Steinberg et al., 2009). A person's tendency to think about the future might directly influence how they make portion size selections, and the extent to which knowledge about the length of an IMI will influence their food intake. Therefore, in determining how future meal timings affect food intake, it is essential to consider individual differences in the extent to which people value the future.

### *1.3.2 Individual differences in future thinking and impulsivity*

The following section will introduce impulsivity, specifically focusing on delay discounting, a measure of future thinking. Research is presented to outline the current understanding of how individual differences in future thinking are linked to eating behaviour and obesity. Impulsivity can be defined as "a tendency to respond quickly to a given stimulus, without deliberation and evaluation of consequences" (Gerbing, Ahadi, & Patton, 1987). It is a behavioural trait implicated in the development and aetiology of a wide-range of 'unhealthy' behaviours, particularly in the psychopathology of addictions (Argyriou, Um, Carron, & Cyders, 2018; de Wit, 2009). Impulsivity has been repeatedly linked with overeating and obesity, both in adults (Appelhans et al., 2012; Appelhans et al., 2011; Davis, Levitan, Muglia, Bewell, & Kennedy, 2004; Epstein, Salvy, Carr, Dearing, & Bickel, 2010; Guerrieri et al., 2007; Kulendran et al., 2013; Nederkoorn, Braet, Van Eijs, Tanghe, & Jansen, 2006; Thamocharan, Lange, Zale, Huffhines, & Fields, 2013; Weller, Cook, Avsar, &

Cox, 2008) and children (Francis & Susman, 2009; Thamocharan et al., 2013). However, impulsivity is a multifaceted trait that may encompass a wide range of behaviours with considerable variation. For example, several manifestations of impulsivity are described in the obesity literature, such as a need for immediate gratification, non-planning, low-future orientation, poor inhibitory control, thrill or novelty seeking, and reward seeking (Khaokhajorn, Samipak, Nithithanasilp, Tanticharoen, & Amnuaykanjanasin, 2015).

Indeed, different measures of impulsivity have been associated with overeating and obesity (Davis et al., 2004; Gerlach, Herpertz, & Loeber, 2015; Giel, Teufel, Junne, Zipfel, & Schag, 2017; Manwaring, Green, Myerson, Strube, & Wilfley, 2011; Nederkoorn, Houben, Hofmann, Roefs, & Jansen, 2010; Rasmussen, Lawyer, & Reilly, 2010; Rollins, Dearing, & Epstein, 2010; Rydén et al., 2004; Weller et al., 2008). However, these associations are often weak, unreliable (Appelhans et al., 2012; Appelhans et al., 2011; Rollins et al., 2010; Weller et al., 2008), or otherwise only observed in particular subgroups, e.g., only women or individuals with binge eating disorder (Giel et al., 2017; Loeber et al., 2011; Nederkoorn, Braet, et al., 2006; Wu et al., 2013). Although there are a broad range of definitions of impulsivity and relevant methods of measurement, this thesis will focus on one facet of impulsivity in particular – future orientation.

Future orientation can be defined as the extent to which one thinks about the future or anticipates the future consequences of a decision. The tendency to act impulsively is associated with a lack of forethought and relatively greater responsiveness to the immediate, rather than the future, consequences of a decision. An individual's capacity to consider the future determines the extent to which they make decisions based on the possible outcomes. Studies have shown that an individual's future perspective influences their tendency to engage in healthy behaviours (Sweeney & Culcea, 2017). People oriented towards the future tend to eat a healthy diet, engage in more regular physical activity and have a low BMI (Adams & Nettle, 2009; Bickel, Jarmolowicz, Mueller, Koffarnus, & Gatchalian, 2012; Hall, Fong, & Cheng, 2012; Weller et al., 2008). Future orientation has

been observed and measured in a variety of ways. One of the most prominent constructs in the literature exploring future orientation and impulsivity, and central to this thesis, is delay discounting.

#### *1.4 Delay Discounting*

Individual differences in future-orientation are typically measured by assessing delay discounting. Delay discounting is a facet of impulsivity that taps into individual differences in future perspective. It is considered a behavioural-economic index of impulsive decision-making (MacKillop et al., 2011), referring to the tendency to respond to the immediate rather than the long-term rewards or consequences of a decision (Moeller, Barratt, Dougherty, Schmitz, & Swann, 2001). Inter-delay decisions were first given attention in the mid-20<sup>th</sup> Century, in the field of economics (da Matta, Gonçalves, & Bizarro, 2012). By 1937, Paul Samuelson proposed the 'Discounted Utility Model', a function that condensed separate drivers of inter-delay choice into a single discount rate (Frederick, Loewenstein, & O'Donoghue, 2002). Definitions of delay discounting vary: some focus on the value of a delayed reward (Tesch & Sanfey, 2008), whereas others focus on the subjective value of a future consequence (Baker, Johnson, & Bickel, 2003). Throughout this thesis, delay discounting will be defined as the tendency to discount future rewards and/or consequences.

Delay discounting rates have since been used in the field of psychology, to reflect individual differences in the extent to which people make decisions about the future. 'Steep' discounters, or highly impulsive individuals, tend to choose immediate rewards over longer-term gains/consequences. Therefore, steep delay discounting is indicative of an individual's inability to consider the future, and instead choose instant gratification. In prioritising the immediate desires, delay discounters diminish the future consequences or benefits of decisions. The well-known 'Marshmallow test' (Mischel, Ebbesen, & Raskoff Zeiss, 1972) exemplifies this perspective – delaying gratification is often especially challenging in children, who tend to choose to eat a single marshmallow immediately rather than waiting for two marshmallows after a delay.

Delay discounting is commonly measured using a behavioural-economic task, where individuals are asked to choose between a small immediate monetary reward (e.g. £50 immediately) and a larger delayed monetary reward (e.g. £200 in one year). Most tasks use a computerised adjusting-amount (AA) procedure (Richards, Zhang, Mitchell, & de Wit, 1999) that systematically manipulates the value of the immediate reward at a range of delay intervals to determine an indifference point (when the delayed reward is chosen over the immediate reward). Indifference points for each delay are plotted to calculate the Area Under the Curve (AUC), a metric of delay discounting (Myerson, Green, & Warusawitharana, 2001). The AUC is the most common measurement of delay discounting, that is shown to be less skewed than other measures, as it is not fitted to a specific model (Myerson et al., 2001). This measure is a calculation of the rate at which the delayed rewards are discounted (See Figure 1.1 for visual illustration of AUC). A smaller area under the curve is indicative of steep delay discounting.

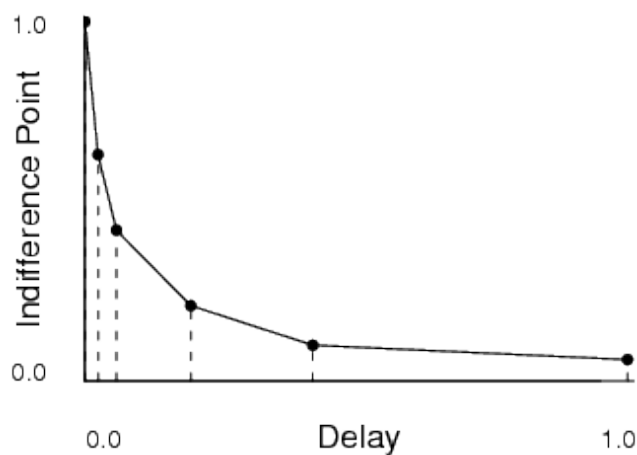


Figure 1.1. Visual depiction of the area under the curve calculation used to quantify discounting. Maximum reward and delay are set to 1. Reprinted from 'Domain-Specific Temporal Discounting and Temptation,' by E. Tsukayama and A. Duckworth, 2010, *Judgment and Decision Making*, 5(2), p. 76.

#### *1.4.1 Clinical relevance of delay discounting*

Delay discounting is considered a 'trans-disease' trait (Bickel et al., 2012) as it is typically associated with various disorders and disease-related vulnerabilities, including ADHD (Hurst, Kepley, McCalla, & Livermore, 2011; Scheres, Lee, & Sumiya, 2008), psychiatric conditions (Bornovalova, Lejuez, Daughters, Zachary Rosenthal, & Lynch, 2005; Gold, Waltz, Prentice, Morris, & Heerey, 2008), depression (Yoon et al., 2007) and gambling (Dixon, Marley, & Jacobs, 2003). Delay discounting has also become highly relevant to the study of addictive behaviour. It is understood that the propensity to discount delayed rewards or consequences underpins addictive behaviours, as steep delay discounting has repeatedly been shown to be more prevalent in those struggling with addictions (Amlung, Vedelago, Acker, Balodis, & MacKillop, 2017; MacKillop et al., 2011; Reynolds, 2006). Furthermore, delay discounting has gained growing attention as a behavioural phenotype that promotes food intake and weight gain. In making dietary choices, people must decide between immediate food rewards and longer-term health consequences. Thus, delay discounting is considered to play an important role in the decisions that contribute to the aetiology and maintenance of obesity (Amlung, Petker, Jackson, Balodis, & MacKillop, 2016). The following section will present evidence for associations between delay discounting with food intake and BMI.

#### *1.4.2 Evidence for associations between delay discounting with obesity, food intake and BMI*

There have been a number of studies assessing the role of delay discounting in obesity. Evidence supports a relationship between delay discounting, food intake and BMI, although findings are relatively inconsistent. Steeper discounting is associated with increased meal size in both lean (Rollins et al., 2010) and overweight women (Appelhans et al., 2011), and has been observed in individuals with higher BMI and body fat percentage, adults with obesity, and those with binge eating disorder (Manwaring et al., 2011; Rasmussen et al., 2010; Weller et al., 2008). Some studies have found a higher incidence of

steep delay discounting in individuals with obesity (Lawyer, Boomhower, & Rasmussen, 2015; Manwaring et al., 2011; Mole et al., 2015; Schiff et al., 2016). Similarly, in continuous designs, high BMI correlated with steeper delay discounting (Chabris, Laibson, Morris, Schuldt, & Taubinsky, 2008; Dassen, Houben, & Jansen, 2015; Epstein et al., 2014; Garza, Ding, Owensby, & Zizza, 2016; Ng et al., 2014). Furthermore, delay discounting is shown to predict obesity intervention outcomes. Children with obesity were less likely to lose weight in a 16-week obesity intervention if they were steep delay discounters (Best et al., 2012). In adults with obesity, shallow delay discounting predicted long-term weight loss success from dieting (Weygandt et al., 2015). However, although there appears to be a link between obesity and delay discounting, the literature is inconsistent.

Several studies have failed to find an association between monetary delay discounting and BMI (Borghans & Golsteyn, 2006; Feda, Roemmich, Roberts, & Epstein, 2015; Rasmussen et al., 2010), binge eating (Manasse et al., 2015), food intake (Appelhans et al., 2011) or obesity (Eisenstein, Gredysa, Antenor–Dorsey, et al., 2015; Manwaring et al., 2011; Nederkoorn, Smulders, Havermans, Roefs, & Jansen, 2006), while another reported a weak relationship between delay discounting and overconsumption (Davis, Patte, Curtis, & Reid, 2010). In a longitudinal study, no association was found between delay discounting and BMI or weight change over 1-3 years in a sample of participants with obesity (Kishinevsky et al., 2012). Additionally, people with high levels of non-planning impulsivity, a facet of impulsivity similar to delay discounting, have been shown to consume less at a test meal (Nasser, Gluck, & Geliebter, 2004), and non-planning impulsivity was shown to inversely predict body fat and binge eating in women (Meule & Platte, 2015). Nevertheless, despite the conflicting evidence, a recent meta-analysis addressed the association between obesity and delay discounting in 39 studies and found relatively strong evidence for a robust association between steep delay monetary discounting and obesity (Amlung et al., 2016). Similarly, a systematic review of 41 studies that focused on assessing the relationship between delay discounting with unhealthy diets, weight change, overweight, obesity and



treatment response concluded that there is moderate evidence to suggest that steep delay discounting is a risk factor for overweight and obesity, as well as the consumption of unhealthy diets (Barlow, Reeves, McKee, Galea, & Stuckler, 2016).

One possible explanation for the inconsistencies in the literature is that studies typically focus on monetary rewards to assess both delay and probability discounting. Although most tasks implement monetary rewards, it has been shown that there are important differences in the extent to which individuals discount food, compared to money. The domain effect postulates that discounting rates vary with commodity type (Baker et al., 2003; Charlton & Fantino, 2008). This is a robust phenomenon, shown with a variety of commodities. When various commodity types have been compared in discounting tasks, food, soda, alcohol and cigarettes are discounted at a higher rate than monetary gains (Charlton & Fantino, 2008; Estle, Green, Myerson, & Holt, 2007; Odum, Baumann, & Rimington, 2006; Odum & Rainaud, 2003). These findings suggest there is a dichotomy between primary and secondary reinforcers, money being a secondary reinforcer and food, alcohol and cigarettes etc. being primary reinforcers (Charlton & Fantino, 2008). Several differences between commodities that are thought to increase the rate of discounting have been identified (Charlton & Fantino, 2008): including high perishability (Odum & Rainaud, 2003), high satiation, low fungibility (Estle et al., 2007) or immediately consumption readiness (Raineri & Rachlin, 1993). Given the vast differences in the characteristics of food compared to money (food has high perishability, high satiation, low fungibility and can be immediately consumed, whereas money cannot), delay discounting of food is likely to differ greatly from discounting of money. It is argued that monetary discounting is not an adequate proxy for food discounting

These differences between food and money are particularly important when designing studies to measure the role of discounting in obesity. Furthermore, evidence suggests that there are commodity-specific discounting patterns in individuals who are addicted to the commodity being discounted; addicts tend to discount their abused

substances more steeply than money (Baker et al., 2003; Coffey, Gudleski, Saladin, & Brady, 2003; Hoffman et al., 2006; Mitchell, Fields, D'Esposito, & Boettiger, 2005). In line with this, people struggling with obesity might discount food, but not money. Indeed, participants with obesity have been shown to discount future weight loss more steeply than money (Sze, Slaven, Bickel, & Epstein, 2017). Therefore, given that delay discounting is likely to be a commodity-specific trait (Charlton & Fantino, 2008; Odum et al., 2006), using monetary tasks to assess delay discounting could mask individual differences in delay discounting of food, especially in people who value food more highly. Thus, it is important that the food-based discounting tasks are implemented to establish the true role of discounting in food intake and obesity. One of the aims of the current thesis was to compare money versus food discounting, to assess whether discounting is indeed a substance-specific trait.

#### *1.4.3 Food discounting tasks*

Given the potential differences between dietary and monetary delay discounting, food-specific delay discounting tasks have been designed. A method of adjustment (adjusting amount for food; AA-F) task has been designed, where participants are asked to choose between 7 bites of their favourite food immediately, or 10 bites of their favourite food at a delay of 1, 2, 5, 10, or 20 hours (Rasmussen et al., 2010). Participants with high body fat % were more likely to discount the future, larger food reward in favour of the immediate smaller reward. A significant positive relationship was found between restrained eating and impulse control in the dorsal-lateral prefrontal cortex using a similar AA-F chocolate-based delay discounting task (Dong. et al., 2016). In a series of trials, participants were given the option of receiving 5 chocolates immediately or 6-20 chocolates at 5 delayed intervals (14, 26, 35, 50, 65 minutes). Discounting of food rewards has been associated with high BMI (Privitera & Dickinson, 2015), high body fat (Hendrickson & Rasmussen, 2013; Hendrickson, Rasmussen, & Lawyer, 2015; Rasmussen et al., 2010), as well as BED and obesity (Manwaring et al., 2011). Furthermore, a vending machine intervention (Appelhans et al., 2018) that imposed a time delay on less healthy snacks successfully increased healthy

snack purchasing (although only by 2%). Following these food-specific delay discounting tasks, a novel task designed to specifically assess discounting of high and low energy food rewards is presented in Study 3 (Chapter 4).

#### *1.4.4 Delay discounting and sensitivity to future meal timings*

The previous section highlighted that there are vast individual differences in the extent to which individuals think about the future consequences of decisions and discussed how these individual differences in delay discounting may influence food intake and BMI. It is possible that sensitivity to anticipated meal timings could be linked to the extent to which people are future orientated when making decisions. Therefore, these two previously unrelated topics will be linked, to explore how future-orientated thinking influences decision making in this context.

There is a great deal to be gained from applying delay discounting concepts to meal planning and portion size research. For example, one of the central aims of this thesis is to explore how information about the length and certainty of an IMI influences decisions about portion size. Evaluating meal planning through the lens of delay discounting, could provide a more theoretical perspective to this hypothesis. One of the fundamental principles of delay discounting is that rewards with a higher value are discounted more steeply (O'Donoghue, 2011). In line with this logic, information about the length or certainty of the IMI could influence the subjective value of the rewards or consequences of eating, which could increase the extent to which the information about the IMI is discounted. Indeed, the reward value of food differs with hunger and fullness, as well as time of day. For example, 10 slices of pizza will have a smaller value just after breakfast has been eaten at 9am and a larger value at 7pm if no food has been consumed all day. Similarly, a food typically eaten at lunch or dinner (e.g. soup) might have a higher value at an appropriate time (such as 1pm), but a lower value at a less appropriate time (such as 8am). Given that the value of food is both state and time-dependent, the extent to which individuals discount the future rewards or consequences of

eating could change with information about the future IMI, which in turn might influence portion size selection.

For the first time, the studies presented in this thesis explore whether the expression and downstream effects of delay discounting manifests in how people respond to information about future meal timings. Similarly, if the value of food is state-dependent (e.g. changes with fullness or hunger), it is likely that delay discounting might also be state-dependent. One of the secondary aims of this thesis is to explore whether discounting is state-dependent, by exploring whether discounting of food and money differs when individuals are fasted or fed.

The experiments reported in Study 1 (Chapter 2) and Study 2 (Chapter 3) also assessed whether individual differences in delay discounting are associated with people's sensitivity to anticipated future meal timings when making portion size decisions. The discounting literature can be criticised for neglecting to consider that delay discounting could have multiple, contrasting effects on eating behaviour. The role of discounting is often framed around a single proposition, that some people lack inhibitory control and find it difficult to resist eating food when it becomes available. However, this may be an oversimplification of the influence of delay discounting on food intake. By characterising impulsivity in this way, other influences on eating behaviour may be overlooked. For example, steep delay discounting could mean that individuals are less concerned about future potential hunger and therefore consume smaller portions, relative to future oriented individuals who may choose larger portions to protect against future hunger. The hypotheses presented in this thesis aimed to explore the different effects of delay discounting on portion size. The experiments will introduce novel tasks that have been designed to measure individual differences in future sensitivity when making dietary decisions about food intake.

### *1.5 Summary, thesis aims and overview*

This chapter has outlined the key terms, concepts and methods which will be used throughout the thesis. Obesity is a global epidemic and understanding the drivers of portion size and food intake is critical to developing interventions to successfully reduce obesity.

Several predictors of food intake have been identified and studies show the future consequences of eating (such as expected satiety) are considered when people make portion-size decisions. However, no studies have shown how anticipated meal timings, specifically the length and certainty of an expected IMI, influence food intake. Critical gaps in the current literature have been established; a lack of understanding of how future meal times influence decision making; limited evidence to support claims that irregular meal timings promote weight gain; and an absence of methods and understanding of how future-orientated thinking influences decision making in this context. Given these limitations, each experimental chapter of this thesis will apply specific and novel methods to address the following research questions:

1. Does the length and certainty of an expected IMI influence decisions about portion size? - Chapter 2 (Study 1), 3 (Study 2) and 4 (Studies 3, 4 and 5)
2. Is there a relationship between delay discounting of money, BMI and IMI sensitivity (the extent to which knowledge of future meal timings influences an individual's portion size selection)? - Chapter 2 (Study 1), 3 (Study 2) and 4 (Studies 3, 4 and 5)
3. What are the underlying factors that explain why individuals adapt their portion size based on the anticipated length of an IMI? - Chapter 4 (Studies 4 and 5)
4. Are individuals with a high BMI more likely to eat at irregular times? - Chapter 5 (Study 6, 7 and 8)
5. Does fasting influence discounting of food and money rewards? - Chapter 6 (Study 9)

## **2 Chapter 2. Study 1.**

### **“What time is my next meal?” Delay-discounting individuals choose smaller portions under conditions of uncertainty**

This chapter is adapted from a paper published in *Appetite* with Zimmerman as first author (Zimmerman et al., 2017). Colleagues Sarah Davies, Ashley Martin and Danielle Ferriday were responsible for the design and implementation of this study. The author of this thesis was responsible for the analysis, interpretation, writing and dissemination of the data reported below.

#### *2.1 Chapter Outline*

In Chapter 1, the importance of understanding food intake and factors that influence portion size decisions were discussed. However, no studies have considered that information about future meal timings might influence food intake. For the first time, this study assesses the effects of the length and certainty of an IMI on computerised portion size selection. The role of delay discounting in eating behaviour and obesity was also presented in Chapter 1. This study is the first to combine the two previously separate areas of delay discounting and meal patterns. Monetary delay discounting is assessed in the context of future meal timings, specifically assessing how individual differences in portion size adjustments made in response to an IMI are related to BMI and monetary delay discounting.

The aims of this chapter are:

1. To assess whether information about the length and certainty of an IMI influences computerised portion selection.
2. To investigate individual differences in sensitivity to the length and certainty of an IMI, and how they relate to individual differences in monetary delay discounting and BMI.

## 2.2 Introduction

Impulsive individuals tend to respond to the immediate rather than the long-term benefits or consequences of a decision (Moeller et al., 2001). A non-future oriented individual who discounts delayed rewards is often described as a 'steep' delay discounter. Steep temporal discounting has been related to an unhealthy diet, overeating and obesity (Barlow et al., 2016; Kulendran et al., 2014; Manwaring et al., 2011; Rollins et al., 2010). Nevertheless, associations are often weak and unreliable (Appelhans et al., 2011; Eisenstein, Gredysa, Antenor-Dorsey, et al., 2015; Hendrickson et al., 2015; Leitch, Morgan, & Yeomans, 2013; Rasmussen et al., 2010; Stoeckel, 2013; Stojek, Fischer, Murphy, & MacKillop, 2014; Weller et al., 2008). One explanation for these inconsistencies is that delay discounting can have multiple effects on food decisions. For instance, steep delay discounters might only eat larger amounts when the immediate reward value is significantly greater than the future reward value but eat smaller amounts when the immediate and delayed reward values are comparable. Alternatively, impulsive people might also eat less when discounting information about future hunger, compared to less impulsive people who might overeat due to concerns about future hunger. However, the role of temporal discounting is often framed around a single proposition; that impulsive people overeat because they discount long-term health consequences (Zhang & Rashad, 2008).

In addition, associations between discounting and overconsumption are often attributed to a lack of concern for long-term weight gain (Barlow et al., 2016). This perspective stands at odds with research (Gregorios-Pippas, Tobler, & Schultz, 2009; McClure, Ericson, Laibson, Loewenstein, & Cohen, 2008; Tanaka et al., 2004), which shows that temporal discounting operates over much shorter delays of seconds and minutes. Recent studies have found that humans also discount the value of food and drink at intervals as short as thirty seconds (Hendrickson & Rasmussen, 2013; Lumley, Stevenson, Oaten, Mahmut, & Yeomans M, 2016; Rasmussen et al., 2010). This indicates that people also discount short-term consequences of dietary decisions, rather than just long-term concerns

about health or weight gain. In the present study the prospect that dietary discounting occurs over an intermediate time frame (hours rather than years) is assessed in the context of portion size selection from one meal to the next.

It was discussed in Chapter 1 that portion size selection is planned prior to eating. Evidence suggests that people typically select a portion to eat and then clean their plate (Fay et al., 2011; Wilkinson et al., 2012), and that plate clearing is predictive of larger body weight (Robinson & Hardman, 2015). Portion size is often governed by the 'expected satiety' of a food – a concern to select an amount that is sufficient to stave off hunger (the desire to eat) in the interval between meals (Brunstrom & Rogers, 2009; Brunstrom, Shakeshaft, et al., 2008). Anticipated meals timings probably influence these decisions. However, no studies have systematically explored this phenomenon and it remains unclear how monetary delay discounting relates to meal planning in this context. To address these questions, the extent to which the length of an IMI influences lunchtime portion-size selection was explored.

One possibility is that meal planning might be less evident in steeper discounters. People plan their behaviours by evaluating the future consequences of a decision (da Matta et al., 2012). However, impulsive decision-makers may fail to consider all relevant information before making a choices (Verplanken & Sato, 2011). Given this logic, it was anticipated that steep delay discounters would be less concerned with the relative consequences of a long or short IMI when making in-the-moment portion-size judgements. Therefore, it was reasoned that steep discounters would show 'certain IMI insensitivity', (a relative lack of concern for potential hunger or fullness during the certain IMIs) and have a smaller difference between portion sizes chosen at a short and long IMI.

In addition, it is interesting to consider the effects of an uncertain IMI. If meal times are irregular, the IMI can be uncertain. Irregular eating is associated with having a higher BMI (Sierra-Johnson et al., 2008) and is thought to be a contributing factor to high-energy intake and weight gain (Berg & Forslund, 2015; Murata, 2000). Unsurprisingly, various dimensions of impulsivity have been associated with irregular or uncertain eating



behaviours, including opportunistic snacking and a preference for snack foods (Fay, White, Finlayson, & King, 2015; Nederkoorn et al., 2010).

The current study assessed individual differences in responsiveness to an uncertain IMI. One possibility is that irregular meal times encourage impulsive behaviours because they generate uncertainty. Uncertainty has been shown to increase delay discounting; individuals discount future rewards more steeply when the delayed event is perceived to be riskier or less certain (Baumann & Odum, 2012; Green & Myerson, 2010; Patak & Reynolds, 2007). It is important to mention that these studies manipulated the likelihood of an event occurring, rather than uncertainty around the exact timing of an event. It is proposed that uncertainty about the timing of an event may also increase discounting. When IMIs are certain, individuals can make predictions about future hunger or satiety. However, when event timings are variable, it is harder to plan for the future (Greville & Buehner, 2010). On this basis, uncertainty may increase discounting of information about future meal timings. To protect against the potential for hunger, individuals who are sensitive to the future might select larger portions when the IMI is uncertain. Conversely, steep discounters may be less responsive. Hence, it was hypothesized that when meal timings were uncertain, steep delay discounters would select portion sizes that are smaller than the average of those chosen when meal times were certain. Evidence for this hypothesis was considered by systematically manipulating the certainty of an IMI and evaluating individual differences in 'uncertain IMI sensitivity' IMI (a relative lack of concern for potential hunger or fullness during the uncertain, compared to certain IMIs).

In the present study portion selection was measured in response to information about the IMI. Participants chose lunch portions in three different conditions; two where the IMI was 'certain' (dinnertime at 5pm and 9pm), and one where the IMI was 'uncertain' (dinnertime at either 5pm or 9pm). A standard monetary delay-discounting task was used to measure individual differences in future-oriented decision-making. The primary hypothesis was that information about future meal timings would influence portion selection at lunchtime. Specifically, it was predicted that portion sizes would differ in each of the three

conditions and that participants would select smaller portions with a certain short IMI, compared to a certain long IMI. In addition, it was hypothesised that participants would select larger portions in response to the uncertain, compared to the certain, IMIs.

Responsiveness to the uncertain future meal times was evaluated from uncertain IMI sensitivity scores - portion size selection in response to the uncertain IMI, compared to the certain IMIs. Similarly, IMI sensitivity scores were calculated from the difference between portion sizes selected at the long vs. short certain IMI. Second, it was proposed that steep money discounting would be associated with sensitivity to the uncertain and certain IMI. When the IMI was certain, it was hypothesized that steep discounters would show a smaller difference between portions chosen at 5pm and 9pm. When the IMI was uncertain, it was expected that steep discounters would select smaller portion sizes than the average of those chosen when meal times were certain. Finally, to explore how individual differences in future-oriented decision-making relates to BMI, relationships between BMI, IMI sensitivity, and monetary delay discounting were assessed.

## *2.3 Methods – Study 1*

### *2.3.1 Participants*

Participants (N= 90; 61 women, 29 men) had a mean age of 21.2 years  $\pm$  4.7 and were healthy staff or undergraduate and postgraduate students at the University of Bristol, recruited through the laboratory volunteer database or as part of a course requirement. Participants were excluded if they were vegetarian or vegan, not fluent in English, taking any medication that might influence appetite or metabolism (except for oral contraceptive pills), or allergic or intolerant to any foods. They received either £5 (Sterling) or course credits in remuneration for their assistance. The protocol was approved by the local Faculty of Science Human Research Ethics Committee.

### *2.3.2 Food images*

Based on previous research (Brunstrom, Collingwood, & Rogers, 2010) two different dishes were selected that are commonly consumed as main meals in the UK: chicken chow

mein and chicken tikka masala with rice. For each dish, a series of 50 images were photographed with portion sizes ranging from 20 kcal to 1000 kcal, in equal 20-kcal steps. The images were taken using a high-resolution digital camera under identical lighting conditions. The meals were photographed on the same white plate (255-mm diameter).

## 2.4 Measures

### 2.4.1 Liking

Participants were shown a 400-kcal portion of the two test foods in a random order. In each trial they responded on a 7-point scale with end anchor points labelled 'extremely dislike' and 'extremely like.'

### 2.4.2 Familiarity

Familiarity was assessed using a food-frequency questionnaire. Again, participants were shown a 400-kcal portion of each food. In turn, they responded to the question 'How often do you eat this meal?' by selecting one of the following options; 'never,' 'less than once a year,' 'yearly,' 'every 2-3 months,' 'monthly,' 'weekly,' or 'daily.' These were coded 1-7 (least to most familiar). A priori, it was decided that participants would be excluded if they were not familiar with the test foods.

### 2.4.3 Appetite

Measures of hunger and fullness were obtained using a 100-mm visual-analogue rating scale headed 'How [hungry/full/thirsty] do you feel right now?', with end anchor points 'not at all' and 'extremely.' All ratings were elicited on a computer.

### 2.4.4 Three Factor Eating Questionnaire

Dietary behaviour was assessed using a computerised version of the 51-item Three Factor Eating Questionnaire (TFEQ; Stunkard & Messick, 1985). The instrument contains 36 items with a yes/no response format, 14 items on a 1-4 response scale and one vertical rating. The relevant items were scored and aggregated into two scales. The two subscales of particular interest for this study were 'cognitive restraint'; conscious control of food

intake to control body weight (e.g. “I do not eat some foods because they make me fat”) and ‘disinhibition’, loss of control over intake (e.g. “Sometimes when I start eating, I just can’t seem to stop”). Respectively, higher scores indicate greater cognitive restraint and disinhibition. Internal-consistency reliability coefficients (Cronbach’s  $\alpha$ ) were found to be above 0.70 and below 0.90 (de Lauzon et al., 2004). The internal-consistency coefficient of the restraint and disinhibition scales in the current study was 0.89.

#### 2.4.5 BMI

To assess BMI, participant’s height and weight were measured at the end of the experiment. BMI was calculated from measured weight/height<sup>2</sup>.

#### 2.4.6 IMI portion size task

Two food images were presented on a VDU. Photographic images were chosen because other computer-based tasks have been shown to predict real food selection (Pouyet, Cuvelier, Benattar, & Giboreau, 2015; Taylor, Yon, & Johnson, 2014). A fixed portion (400 kcal) of chicken tikka masala was presented on the right and labelled ‘This meal for dinner.’ A portion of chow mein was presented on the left and labelled ‘This meal for lunch.’ The chow mein lunch portion could be increased or decreased by depressing the right or left arrow-keys, respectively. In each trial the participants responded to the question ‘How much would you eat for lunch RIGHT NOW if you had to eat all of the food on the right for dinner at...[time inserted].’ In two of the trials the IMI was ‘certain.’ In one certain trial they were told to expect their evening meal at 5pm. In the other they were told to expect it at 9pm. In a third trial the IMI was ‘uncertain’ - they were told to expect the meal at either 5pm or 9pm. Participants completed a total of three trials. The order of the trials was randomised across participants and each trial started with a randomly selected portion of chow mein.

To calculate certain IMI sensitivity, the difference between portion sizes calculated at the long and short IMI was measured. To assess whether participants were more responsive to the uncertain future meal times (uncertain IMI sensitivity), portions selected at the certain

IMIs were compared with those selected in the uncertain conditions. The uncertain IMI was framed around the same time points as the two certain IMIs (5pm and 9pm). Therefore, the effect of uncertainty can be established by comparing portions chosen in the uncertain condition with average of the portions chosen in the two certain condition. Specifically, uncertain IMI sensitivity was computed based on the following calculation:  $\text{uncertain 5pm or 9pm} - (\text{certain 5pm} + \text{certain 9pm})/2$ . This provides a measure of the effect of uncertainty (relative to certainty) on portion selection. A separate uncertain IMI sensitivity score was calculated for each participant. A positive score indicates that larger portions were chosen in the uncertain condition, compared to the average of the two portions selected in the certain conditions. Higher scores therefore reflect greater uncertain IMI sensitivity.

#### *2.4.7 Monetary delay discounting task*

Delay discounting was measured using a computerised forced-choice task (c.f. Du, Green, & Myerson, 2002). In a series of trials participants indicated whether they preferred to receive a hypothetical delayed reward of £100 after a fixed interval (e.g. 1 year) or a smaller monetary amount immediately. Participants completed several blocks of 10 trials. In every trial the delayed reward was always £100. In the first trial of each block the immediate reward was half the delayed value (£50). If the participant selected the immediate reward, it was adjusted down to £16.66 (33.3% of its original value) in the second trial. If the participant selected the delayed reward, then it was adjusted up to £83.33 (the same difference = £33.33). The same rationale was applied in subsequent trials (trials 3-10). However, in each trial the adjustment amount decreased by 33.3% (i.e., from £33.33 in trial 2 to £22.22 trial 3, from £22.21 in trial 3 to £14.81 trial 4, and so on). This single 'staircase' approach progressively converged around a point of indifference in which the delayed and immediate amounts are equally likely to be selected.

Initially, three practice blocks were presented. In order, the hypothetical delays were 2 years, 1 year, and 6 months. This was followed by six further blocks. Each presented a scenario with one of the following delays; 2 days, 7 days, 30 days, 6 months, 1 year, 2

years. The order of these blocks was randomised across participants and responses were used to calculate a measure of delay discounting. The delay-discounting task and the IMI portion task were implemented using custom software (available on request) written in Visual Basic (Microsoft version 6.0). For each participant, a measure of delay discounting was obtained from area under the curve (AUC) values derived from the delay-discounting task (c.f. Myerson et al., 2001). AUC values were calculated using the trapezoid method. Smaller AUC values indicate steeper delay discounting.

## *2.5 Procedure*

Participants completed one 45-minute session between 12pm and 2pm. On arrival they reported how long ago they last ate and then rated their appetite and thirst. They then completed the IMI portion task, followed by liking and familiarity ratings, and the delay-discounting task. Finally, participants completed the TFEQ and BMI were measured. At the end of the study the participants were debriefed and thanked for their assistance.

## *2.6 Data analysis*

First, to determine whether portion-size selection was influenced by information about the IMI, a one-way, repeated-measures ANCOVA was conducted with three conditions (portion size when the IMI was short, long and uncertain). Gender was included as a between-subjects factor and BMI and age were included as covariates, as gender, BMI and age might influence the portion size judgements of participants or the extent to which they adjust portion sizes with information about the IMI. A paired t-test was used to evaluate specific differences across participants between portion sizes chosen in the long and short certain conditions. Additionally, a paired t-test was carried out to assess whether portion size selection was greater in response to the uncertain, compared to the average of the certain IMIs. Second, to explore the secondary hypotheses, that steep delay discounters would be less sensitive to future IMIs, Pearson's correlation between monetary delay discounting and uncertain IMI sensitivity scores were assessed. Third, relationships between BMI, uncertain IMI sensitivity scores and delay discounting were evaluated.

Post-hoc analyses were carried out to assess whether the portion sizes selected at the uncertain IMI were significantly different from those selected at the short-certain IMI or the long certain IMI. Two paired-samples t-tests were conducted comparing the portion sizes selected at the uncertain IMI with portions selected at the short and long, certain IMIs. Similarly, post-hoc analyses were conducted to investigate whether individual differences in delay discounting moderated the relationship between BMI and portion-size selection in uncertain IMIs. For a moderating relationship to be confirmed when the moderator is controlled for in a regression of the IV on the DV, the  $\beta$ -value relating the IV to the DV becomes insignificant. In the analysis, the uncertain IMI sensitivity scores were entered as the IV, BMI as the DV, and delay discounting as the moderator. All data were analysed using IBM SPSS statistics version 21 (IBM, New York, USA).

## *2.7 Results*

### *2.7.1 Participant characteristics*

There were no outliers in the data, as assessed by inspection of boxplots and standard deviations. There were fifteen participants who were excluded for indicated that they had eaten either of the test foods either 'never', or 'less than once a year'. A further five participants were excluded for selecting the minimum portion of chow mein (20 kcal) for lunch, in every condition. This may reflect a technical error or otherwise a problem in understanding the requirements of the tasks. Finally, six participants had missing data for the delay-discounting task due to a technical error. In these cases, values were entered as missing data. The final dataset comprised 70 participants (46 women, 24 men), with a mean age of 21.0 years  $\pm$  4.2, and a mean BMI = 21.68  $\pm$  2.6 kg/m<sup>2</sup>. In total, 7 participants were underweight, 55 participants were lean and 8 were overweight. See Table 2.1 shows mean scores for liking, appetite, TFEQ, and familiarity, as well as participant characteristics. Both BMI and delay discounting AUC scores were not related to liking, hunger, fullness, familiarity, restraint or disinhibition (See Table 2.2). Mean TFEQ-restraint score (M = 6.7

$\pm 3.6$ ) and mean TFEQ-disinhibition score ( $M = 6.3$ ,  $SD = 2.6$ ) were all in the low range (Lesdema et al., 2012; Stunkard & Messick, 1985).

Table 2.1. Means  $\pm$  standard deviations for participant characteristics, questionnaires, ratings and delay discounting AUC ( $N = 70$ ; 46 women, 24 men).

Measure (units/range)	Mean $\pm$ SD	Range (min-max)
Age (y)	21.0 $\pm$ 4.2	18.0 – 43.0
BMI (kg/m <sup>2</sup> )	21.7 $\pm$ 2.6	16.7 – 27.1
Mean (kcal) short IMI $\pm$ SD	423.4 $\pm$ 217.1	40.0 – 960.0
Mean (kcal) long IMI $\pm$ SD	549.1 $\pm$ 205.3	140.0 – 1000.0
Mean (kcal) uncertain IMI $\pm$ SD	490.94 $\pm$ 190.7	120.0 – 940.0
TFEQ-restraint (0 - 21)	6.7 $\pm$ 3.6	1.0 – 17.0
TFEQ-disinhibition (0 - 16)	6.3 $\pm$ 2.6	1.0 – 13.0
Delay discounting (AUC)	0.6 $\pm$ 0.2	0.0 – 1.0
Appetite (1-7)	5.0 $\pm$ 1.73	1.0 – 7.0
Familiarity (chicken tikka and chow mein, 2-14)	9.8 $\pm$ 1.33	2.0 – 14.0

### 2.7.2 Effect of IMI length on portion size

The analysis revealed a main effect of IMI on portion selection after controlling for age, gender and BMI,  $F(2,132) = 4.53$ ,  $p = 0.012$ ,  $\eta^2 = 0.06$ . Specifically, participants chose larger portions with a certain long IMI (dinner at 9pm;  $M = 549.1$  kcal,  $\pm 205.3$ ) than a short certain IMI (dinner at 5pm;  $M = 423.4$  kcal  $\pm 217.1$ ),  $t(69) = 6.02$ ,  $p = 0.00$ . Covariates predicted to influence portion selection, such as age, gender and BMI did not predict variance in portion selection.

There was no evidence to suggest that participants selected larger portions in response to the uncertain IMI ( $M = 490.9$ ,  $SD = 190.7$ ), compared to the average of the



certain IMIs ( $M = 186.3$ ,  $SD = 192.3$ ),  $t(70) = -0.35$ ,  $p = 0.73$ . See Table 2.1 for mean portion sizes at each IMI.

Table 2.2. Relationships (Pearson's correlations) between IMI index score, delay discounting area under the curve (AUC), TFEQ, BMI, liking, hunger, and fullness.

	Uncertain IMI sensitivity	Certain IMI sensitivity	Delay discounting	TFEQ-Disinhibition	TFEQ-Restraint	BMI	Liking	Fullness	Hunger
Uncertain IMI sensitivity		0.01	0.29*	0.18	-0.01	-0.27*	-0.20	0.16	-0.14
Certain IMI sensitivity			0.18	-0.03	-0.10	-0.23	-0.09	0.18	-0.17
Delay discounting AUC				0.17	-0.03	-0.40**	-0.13	0.11	0.05
TFEQ-Disinhibition					0.13	-0.16	-0.09	0.02	-0.03
TFEQ-Restraint						0.29*	-0.11	0.03	-0.12

BMI	0.04	0.14	-0.08
Liking		-0.07	0.11
Fullness			-0.74**
Hunger			

\*  $p < 0.05$

\*\*  $p < 0.01$

### 2.7.3 Correlations between delay discounting, BMI and portion selection at the certain IMI

There was no evidence for correlations between monetary delay discounting AUC and certain IMI sensitivity,  $r(62) = 0.18$ ,  $p = 0.15^1$ , or between BMI and certain IMI sensitivity,  $r(70) = -0.23$ ,  $p = 0.06$ .

### 2.7.4 Correlations between delay discounting, BMI and portion size selection at the uncertain IMI

Consistent with the hypothesis, there was a significant positive correlation between delay discounting AUC and uncertain IMI sensitivity scores,  $r(62) = 0.29$ ,  $p = 0.02^1$ .

Participants who exhibited steeper monetary discounting (lower AUC) chose smaller portions when the IMI was uncertain than when it was certain (See Figure 2.1). There was a

significant negative correlation between BMI and uncertain IMI sensitivity scores,  $r(69) = -0.27$ ,  $p = 0.03$ . Individuals with a high BMI chose smaller portions when the IMI was uncertain, compared to when it was certain (See Figure 2.2). There was also a significant negative correlation between BMI and delay discounting AUC,  $r(62) = -0.40$ ,  $p = 0.001$ .

Participants who showed steeper discounting had a higher BMI than those with shallower

<sup>1</sup> Degrees of freedom differ due to missing data

discounting. In addition, there was little evidence for correlations between uncertain IMI sensitivity scores with liking, fullness, TFEQ-restraint and TFEQ-disinhibition (see Table 2.2).

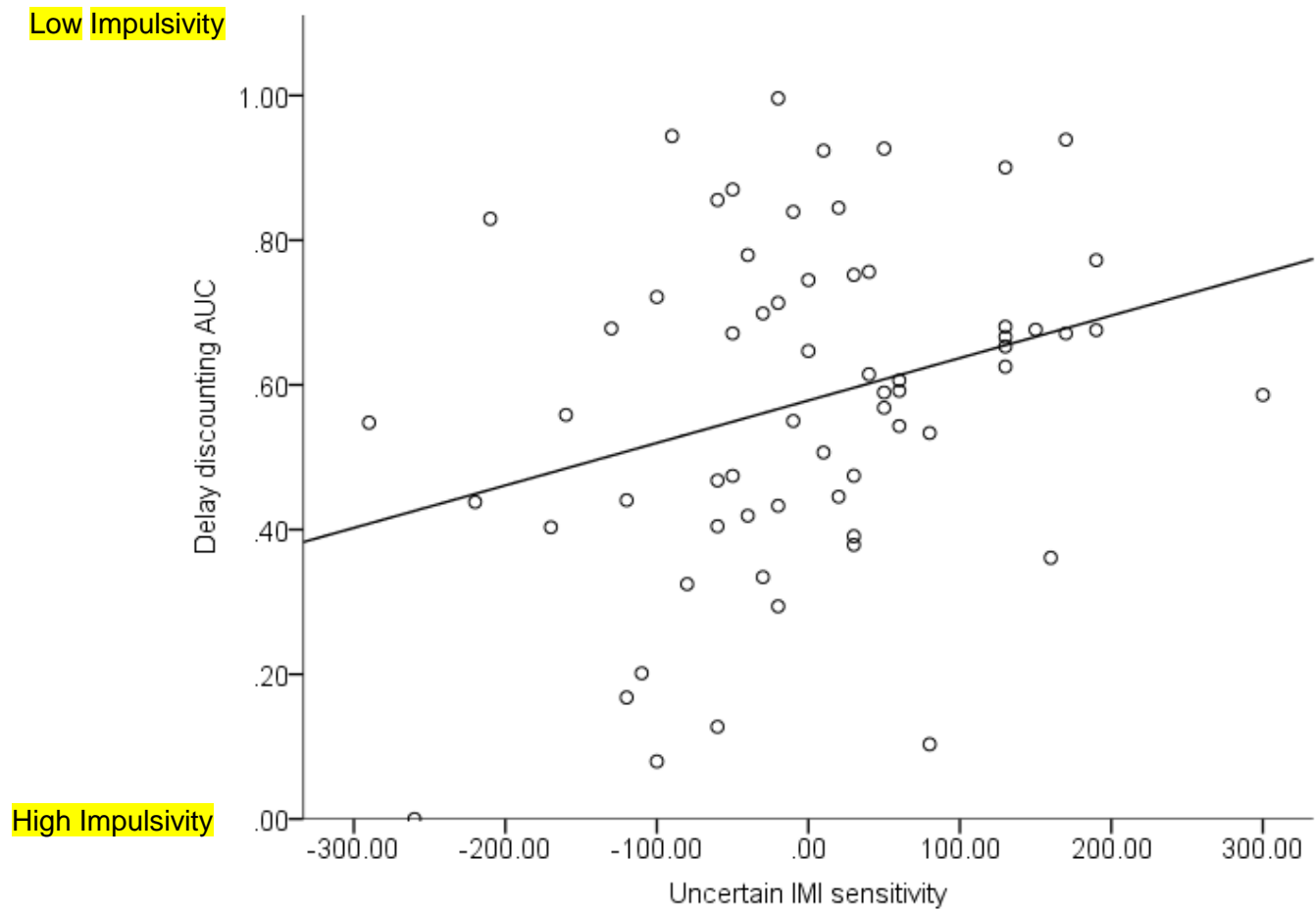


Figure 2.1. Relationship between delay discounting AUC and uncertain IMI sensitivity. Each point represents a single participant. The line represents a best linear fit.

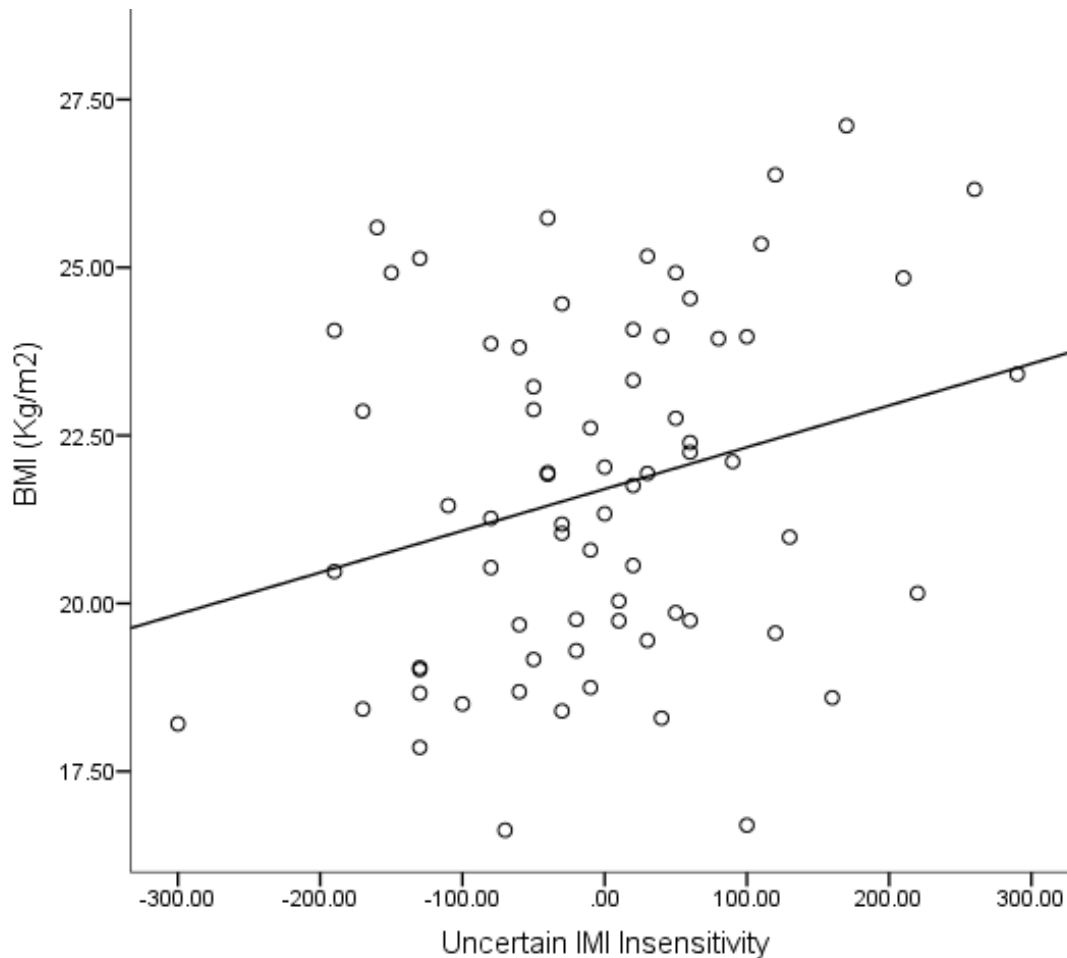


Figure 2.2. Correlation between BMI and uncertain IMI sensitivity. As smaller IMI sensitivity scores reflect greater insensitivity, IMI sensitivity have been flipped (depicting insensitivity) to visually illustrate the linear relationship. Each point represents a single participant. The line represents a best linear fit.

#### 2.7.5 Post-hoc comparison of portion size at the uncertain and each certain IMI

To explore whether portion sizes difference at each IMI, paired-samples t-tests were conducted between portion sizes selected at the uncertain vs. short-certain IMI and the uncertain vs. long-certain IMI. There was a significant difference between portion size at the uncertain IMI and the short-certain IMI,  $t(69) = -3.99$ ,  $p = 0.00$ ; and the long-certain IMI,  $t(69) = 3.5$ ,  $p = 0.001$ . This demonstrates that portion size selected in response to the uncertain IMI was significantly larger than the portions selected at the short-certain IMI, but significantly smaller than portions selected at the long-certain IMI.

### 2.7.6 Post-hoc moderation analysis

To confirm whether delay discounting AUC moderates the relationship between uncertain IMI sensitivity and BMI, multiple regression analyses were carried out. Significant relationships were confirmed between uncertain IMI sensitivity and BMI,  $\beta = -0.26$ ,  $p = 0.03$ , between delay discounting AUC and uncertain IMI sensitivity,  $\beta = 0.29$ ,  $p = 0.02$ , and between delay discounting AUC and BMI,  $\beta = -0.40$ ,  $p = 0.00$ . When delay discounting AUC was controlled for in a regression of uncertain IMI sensitivity scores on BMI, uncertain IMI sensitivity no longer predicted BMI,  $\beta = -0.14$ ,  $p = 0.27$ . This suggests that delay discounting moderates the relationship between BMI and smaller portion size selection at the uncertain, relative to certain, IMIs. Figure 2.3 shows the regression coefficients associated with tests of the relationship between uncertain IMI sensitivity with BMI and delay discounting AUC as a moderator.

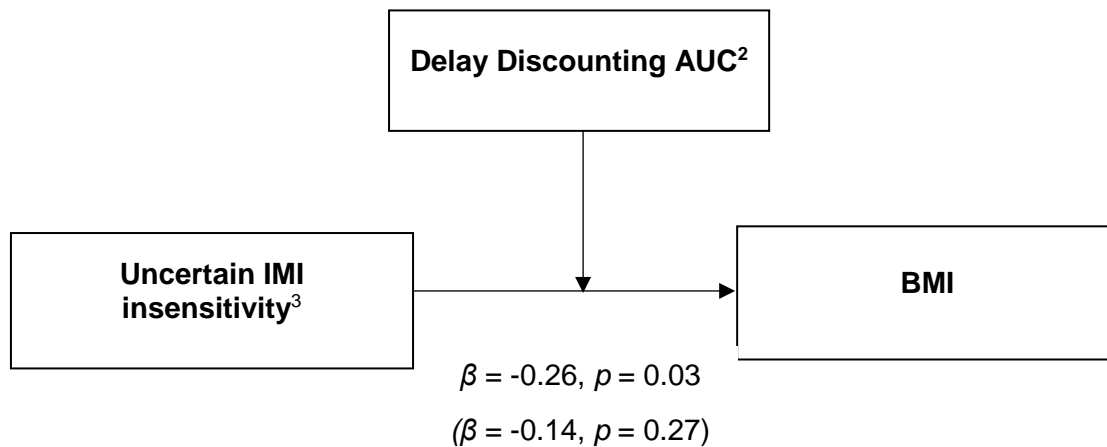


Figure 2.3. Delay discounting AUC<sup>2</sup> as a moderator of the relationship between selection of smaller portion sizes at the uncertain IMI (uncertain IMI sensitivity<sup>3</sup>) and BMI.

Unstandardized  $\beta$  and  $p$  values are shown for the relationship before and after moderation.

<sup>2</sup> Negatively scored (lower scores reflect greater discounting)

<sup>3</sup> Negatively scored (lower scores reflect greater IMI sensitivity)

### *2.7.7 Post-hoc power calculation*

To assess satisfactory statistical power, a post hoc power analysis was conducted. The medium effect size states that the study was underpowered to detect an association between delay discounting and the difference between portion sizes selected at the certain IMIs. The calculation revealed a sample size of 240 would be required to detect this effect with an  $\alpha$  of 0.05 and a  $1-\beta$  of 0.80.

## *2.8 Discussion*

This study assessed how information about IMIs influences portion size decisions and whether steep delay discounters respond differently to the length and certainty of an IMI. The primary hypothesis was that information about future IMIs would influence portion size decisions. Consistent with the first hypothesis, participants chose larger portions in response to the certain long IMI than in response to the certain short IMI. This is the first demonstration that people use information about future meal timings to make in-the-moment decisions about how much to eat. There was no significant difference between the portion sizes chosen at the uncertain IMI, compared to the average of the certain IMIs. However, a post-hoc analysis showed that uncertain portion size selections were larger than portions chosen in response to the short IMI, but shorter than those chosen in response to the long IMI. This suggests that uncertainty does have a significant effect of portion decisions but does not lead to the selection of abnormally large portions. One possible explanation for this is that participants were not actually uncertain about the timing of their next meal, and so participants were not concerned about when they would next eat. To understand the true effect of uncertainty on portion selection, the task should be replicated with real IMIs that generate genuine uncertainty.

Secondly, it was hypothesised that steep monetary delay discounters would be less sensitive to information about the duration of the certain IMIs and show a small difference between portions selected in the long and short IMIs. It was predicted steep discounters would show even greater disregard for future meal times in the uncertain IMI. Greater

monetary delay discounting was associated with smaller portion selection in response to the uncertain IMI, compared to the average of those chosen in the certain IMIs. It is suggested that shallow discounters selected larger portions to protect against possible hunger during the IMI. Consistent with the hypothesis, steep delay discounters appeared to be less sensitive to information about the uncertain IMI, possibly due to a lack of concern for potential hunger between meals. However, steep and shallow discounters selected similar portion sizes when the IMI was certain, suggesting that delay discounting is less relevant when an IMI is known. In line with this idea, individuals show greater discounting of a future reward when the occurrence of a delayed event is less certain (Baumann & Odum, 2012; Green & Myerson, 2010; Patak & Reynolds, 2007). These results suggest that variability in the timing of the event also increases discounting. In the future, researchers should differentiate between irregular eating in the presence or absence of uncertainty. These observations suggest that dietary discounting is more likely to be expressed when meal times are uncertain. Hence, a distinction between certain and uncertain meal timings might be helpful, especially in studies seeking to understand relationships between chaotic eating, discounting and BMI.

It was also predicted that steep discounters, and those with a higher BMI, would be less likely to plan their meals based on the duration of the certain IMI. However, the relationships between certain IMI sensitivity with both BMI and delay discounting were not statistically significant. Although the relationships failed to reach statistical significance, the effect sizes indicate a small-to-medium sized association, suggesting that the current study was potentially underpowered (a sample size of 240 would be required to detect a relationship between certain IMI sensitivity and delay discounting, with an  $\alpha$  of 0.05 and a  $1-\beta$  of 0.80). Further research in a larger sample with a high BMI range is required to assess the relationship between certain IMI sensitivity with BMI and delay discounting.

Temporal discounting is generally regarded as a trait that promotes overconsumption. These findings show that delay discounting might reduce self-selected portion size.

Specifically, the expression and downstream effects of discounting might depend upon whether a meal is planned and whether an IMI is certain or uncertain. These results could help to explain previous inconsistent associations between delay discounting and eating behaviour. Dietary discounting is typically conceptualised as a trade-off between immediate food reward and long-term future health costs. This data suggests that discounting is also expressed in shorter-term delays from one meal to the next. These distinctions are subtle yet potentially essential to our understanding of how delay discounting interacts with eating behaviour across the day and real-world future thinking about meal timings. However, these differences in the certainty and lengths of delays are generally overlooked in studies exploring the acute effects of temporal discounting on food intake. A more nuanced understanding of how meal timings influence future-oriented decisions will contribute to the development of an evidence base, which can inform guidelines around structured eating and meal planning.

The post-hoc analysis suggests that delay discounting moderated the relationship between having a higher BMI and selecting smaller portions with an uncertain IMI. Thus, impulsivity partially explains why individuals with a high BMI were less sensitive to the uncertain IMI. This appears counterintuitive; steep discounters had higher BMIs yet chose smaller portions. One possibility is that a lack of concern for future hunger promotes various compensatory behaviours, such as the selection of energy-dense snacks between meals. In line with this, both chaotic eating and impulsivity have been associated with a greater tendency to snack between meals (Fay et al., 2015) and also greater consumption of palatable foods (Lumley et al., 2016). Further research is required to determine whether snacking behaviour is more prevalent in individuals who less sensitive to information about IMIs.

The study may be limited by using computer-based judgements of food decisions. Nevertheless, the focus of the study was to understand relationships between discounting and meal planning. Although computer-based portion judgments are shown to be predictive



of real food intake (Pouyet et al., 2015; Taylor et al., 2014), it remains to be determined whether the same relationships might be observed in a study of food intake. This was beyond the scope of the present study but might be considered in future research. The IMI task only compared two different certain IMIs, limiting the opportunity to draw conclusions about obesity and sensitivity to meal timings. Additionally, as participants were university students with a relatively narrow range of BMIs, the generalizability of our findings remains unclear. It would be interesting to repeat this study in a sample more representative of the general population, to assess whether individuals with obesity respond to information about future meal timings differently from individuals with a 'normal' BMI. Furthermore, the generalisability of these conclusions that delay discounters are less sensitive to information about future meal timings are somewhat limited by the lack of statistical power. Finally, as mood is shown to influence delay discounting (Koff & Lucas, 2011), subsequent studies could assess how mood influences decision-making regarding discounting of meal timings.

## *2.9 Chapter Summary*

In this study (Chapter 2) the influence of the length and certainty of an IMI on computerised portion size decisions was assessed. Findings confirmed that individuals select larger portion sizes when confronted with a longer IMI. In addition, results showed that steep delay discounters, and those with a higher BMI, selected smaller portions in response to an uncertain IMI, compared to the certain IMIs. Delay discounting moderated the relationship between high BMI and reduced uncertain IMI sensitivity. It is reasoned that in conditions of uncertainty, non-future oriented individuals were less concerned with potential hunger or fullness between meals and selected how much they would like in the moment. These results suggest that delay discounting is more likely to be expressed in a 'chaotic' eating environment. However, all participants had a BMI in the 'normal' range, and the number of IMIs was limited. Consequentially, the next chapter will continue to explore how short-term discounting can influence portion-size decisions by assessing the relationships

between BMI, delay discounting and IMI sensitivity in a wider sample and with a greater range of future meal timings, to improve generalizability of these conclusions.

### *2.10 Acknowledgments*

Work conducted at the University of Bristol was supported by the Biotechnology and Biological Sciences Research Council (BBSRC, grant references BB/I012370/1 and BB/J00562/1). The research of Brunstrom, Rogers, and Zimmerman is currently supported by the European Union Seventh Framework Programme (FP7/2007–2013 under Grant Agreement 607310 [Nudge-it]).

### 3 Chapter 3. Study 2

#### **Obese and overweight individuals are less sensitive to information about meal times in portion size judgements**

This chapter is adapted from a paper published in the International Journal of Obesity with Zimmerman as first author (Zimmerman, Mason, Rogers, & Brunstrom, 2018). The author shared responsibility for participant recruitment, and data collection with Alice Mason. The author was solely responsible for design, analysis, interpretation, writing and dissemination of the data reported below. This experiment is the same as Study 7 (Chapter 5), with a smaller sample due to restrictions participants who were tested at lunchtime.

#### *3.1 Chapter Outline*

In Study 1 (Chapter 2), it was shown that information about the length of an IMI allows meal planning, which influences portion size selection. Steep monetary delay discounters, and those with a high BMI, selected smaller portions in response to an uncertain IMI. Furthermore, monetary delay discounting moderated the relationship between sensitivity to uncertain portion sizes and BMI. There was little evidence for a significant relationship between certain IMI sensitivity with BMI or monetary delay discounting, though the study was not sufficiently powered to detect an effect. It was concluded that these individuals were less sensitive about potential fullness or hunger during the IMI, especially when uncertain, and instead ate how much they would like in the moment. However, the sample had a small range of BMIs, making it difficult to draw conclusions about how an individual's sensitivity to meal timings and future-orientation relates to their BMI. A key aim of this chapter is to assess how obese, overweight, and lean people select portion sizes based on the length of an IMI. In addition, the relationship between certain IMI sensitivity and monetary temporal discounting is considered.

The aims of this chapter are:

1. To replicate the findings in Study 1 (Chapter 2), that participants would choose larger portion sizes when confronted with a longer IMI.
2. To assess whether IMI sensitivity predicts BMI in a sample with 'normal', overweight and obese BMIs.
3. To support the findings in Study 1 (Chapter 2) that both reduced IMI sensitivity and monetary discounting would predict BMI and explore whether monetary discounting moderates the relationship between IMI sensitivity and BMI.

### 3.2 *Introduction*

The present chapter investigated how the length of an IMI influences lunchtime portion-size selection decisions in obese, overweight, and lean participants. Of interest is how individuals differ in their sensitivity to information about the duration of an IMI. People plan their behaviours by evaluating the future consequences of a decision (da Matta et al., 2012). However, impulsive decision-makers might not consider all prospective information before making a decision (Verplanken & Sato, 2011). Impulsivity, specifically delay discounting, has been implicated as a risk factor for weight gain, obesity, addictive behaviours (For reviews, see Amlung et al., 2016; Amlung et al., 2017; Barlow et al., 2016; MacKillop et al., 2011). As explained in Study 1 (Chapter 2), although the relationship between obesity and monetary discounting has been widely researched, the findings have been variable, with the observed associations being weak or present only in women (Appelhans et al., 2012; Eisenstein, Gredysa, Antenor–Dorsey, et al., 2015; Hendrickson et al., 2015; Rasmussen et al., 2010; Stoeckel, 2013; Stojek et al., 2014; Weller et al., 2008).

One explanation for these inconsistencies is that monetary discounting is a poor proxy for the tendency to discount the future consequences of consuming food (Barlow et al., 2016; Critchfield & Kollins, 2001). Evidence suggests that money and food are discounted differently; food tends to be valued as more rewarding and discounted at a higher rate than money (Charlton & Fantino, 2008; Odum et al., 2006; Odum & Rainaud, 2003). As discussed in Study 1 (Chapter 2), one critical difference is that dietary discounting has been shown to

occur over a short timeframe, whereas monetary discounting is often considered over long periods. These findings indicate that people also discount the shorter-term consequences of dietary decisions, rather than only long-term concerns about health or weight gain. An additional difference is that the future value of food, unlike money, is not stable and may depend on the timing of a person's next meal. For example, a large portion might be less desirable if a person plans to eat again in thirty minutes. As such, the value of food, and therefore the rate of discounting, may be dependent on short-term future meal planning. Furthermore, dietary discounting appears to be a more consistent predictor of BMI than discounting of money (Amlung et al., 2016; Rasmussen et al., 2010); studies have found discounting of food, but not money, to be associated with body fat percentage and impulsive eating behaviours (Houben, Nederkoorn, & Jansen, 2014; Rasmussen et al., 2010). Therefore, food-based discounting tasks may be more relevant to eating behaviour and obesity (Dassen et al., 2015). With the differences between dietary and monetary discounting tasks in mind, it is critical to isolate how discounting manifests in decisions about food. This chapter aimed to further explore the extent to which meal timings are discounted when making dietary decisions.

In Study 1 (Chapter 2), for the first time, the relationship between monetary delay discounting, BMI and IMI insensitivity was explored. Non-future-oriented individuals, and those with a high BMI, were less sensitive to information about the length and certainty of an IMI when selecting portion sizes. It was reasoned that steep delay discounters selected smaller portions because they were less sensitive to the uncertain IMI and overlooked concerns about potential future hunger/fullness. Moreover, monetary discounting moderated the relationship between high BMI and smaller portion size in response to the uncertain IMI. This suggests that delay discounting might reduce sensitivity to uncertain meal timings and, in turn, lead to increased food intake and weight gain. However, these findings cannot be generalised to the wider population, as participants had a relatively narrow range of BMIs.

Thus, it is important to evaluate the relationship between delay discounting, BMI and sensitivity to anticipated meal timings in a sample with a wide range of BMIs.

The aim of this chapter was to assess whether individuals with a high BMI differ in their sensitivity to certain meal timings when making portion size decisions. It is predicted that individuals with obesity would be less sensitive to information about future timings. Those with a high BMI might be more concerned with how much they want to eat in the moment and, therefore show lower sensitivity to information about future meal timings. Indeed, obesity has been related to poor future episodic thinking about food (Daniel, Stanton, & Epstein, 2013). In contrast, it was predicted that 'normal' weight individuals would be more future-oriented and plan for potential meals, so are more sensitive to information about the length of the IMI.

Alternatively, individuals with a high BMI could have a higher tolerance for hunger and fullness. Previous studies have shown that BMI is related to poor interoceptive awareness (Herbert, Blechert, Hautzinger, Matthias, & Herbert, 2013). This refers to the ability to perceive one's internal state. Specifically, body weight has been associated with insensitivity to visceral cues of hunger and satiety (Herbert & Pollatos, 2014; Stunkard., 1959). It is possible that bodily signals are not important drivers of portion size decisions in obese individuals. For instance, participants with a high BMI may not imagine they would feel hungry when the prospective IMIs are longer and select smaller portions accordingly.

Furthermore, the study aimed to investigate whether BMI and monetary delay discounting influence how people respond to the predictability of an IMI. It is possible that uncertainty might increase the likelihood that a steep delay discounter will make an impulsive decision that is motivated by immediate short-term concerns. In line with this, impulsive people show even greater discounting of a future reward when the delayed event is less certain (Baumann & Odum, 2012; Green & Myerson, 2010; Patak & Reynolds, 2007). Results from Study 1 (Chapter 2) showed that individuals with high delay discounting and BMI selected smaller portions in response to an uncertain IMI. This supports the possibility

that uncertainty may lead impulsive individuals to discount the future more steeply. With the aim of replicating this finding in a sample with a wider BMI range, it was predicted that individuals with obesity, and steeper delay discounters, will select smaller portions when the IMI is uncertain, whereas normal-weight individuals will select larger portions.

A potential weakness of Study 1 (Chapter 2) is that only two different certain IMIs were compared, limiting the opportunity to draw conclusions about obesity and sensitivity to meal timings. In addition, portion size decisions were made about only one type of food, thus limiting the generalisability of the findings. In this study, the aim was to improve these issues by asking participants to evaluate decisions across a range of foods and IMIs. First, the number of different certain IMI lengths were increased to improve the sensitivity of monetary discounting tasks. The monetary delay discounting tasks were mirrored, which uses 6 different future reward timings to generate an AUC that reflects discounting. By increasing the number of IMIs, a more nuanced measurement tool can be established that should tap into more subtle individual differences in certain IMI sensitivity. Second, portion-size judgements of a greater range of foods were measured; selection of a HED and LED foods in response to a future savoury and sweet meal. Initially, the range of foods were increased to improve the generalisability of the task. This has the added benefit of being able to assess whether certain IMI sensitivity would differ between the high and low energy portions or sweet and savoury foods.

The present chapter investigated how the length of an IMI influences lunchtime portion-size selection decisions in obese, overweight, and lean participants. As in previous studies (Amlung et al., 2016), BMI was included as a continuous measure in the analysis. To assess the extent to which participants are sensitive to future meal times, lunchtime portion-size selection was measured using a computerized task and systematically manipulated the timing of the following meal. From this, a measure of certain IMI sensitivity was derived that reflects the tendency to discount information about IMI when selecting portion-sizes. To evaluate decisions across a range of foods, portion-size judgements of high and low-calorie

foods were measured in response to a future savoury and sweet meal. In addition, to assess whether reduced certain IMI sensitivity reflected a conscious lack of concern about fullness or hunger, participants were asked to report whether they considered hunger and fullness in making the decisions.

The novel hypothesis that shorter-term discounting is evident in the selection of portion sizes from one meal to the next was tested. First, it was predicted that participants would choose larger portion sizes when confronted with a longer IMI. To assess whether energy density influenced certain IMI sensitivity, differences in sensitivity to meal timings were compared when selecting low energy density (LED) and high energy density (HED) portions. Second it was hypothesized that with this more sensitive measure, reduced certain IMI sensitivity would predict BMI. It was hypothesized that individuals with a high BMI would discount the length of an IMI when making portion selections. Third, in line with findings from Study 1 (Chapter 2), it was predicted that the inverse relationship between certain IMI sensitivity and BMI would be moderated by monetary delay discounting. Finally, based on the findings from Study 1 (Chapter 2), it was predicted that steep monetary delay discounters, and those with a high BMI, would select smaller portions in response to the uncertain IMI.

### *3.3 Methods – Study 2*

#### *3.3.1 Participants*

Participants (N= 88; 53 females, 34 males, 1 transgender) had a mean age of 32.4 years  $\pm$  11.1 and a mean BMI of 27.7 kg/m<sup>2</sup>  $\pm$  6.7. All participants were members of the public, recruited through our laboratory volunteer database. To reduce demand awareness, participants were told that the purpose of the study was to explore ‘decision making and food preferences’. Participants were excluded if they were vegetarian or vegan, not fluent in English, taking any medication that might influence appetite or metabolism (with the exception of oral contraceptive pills), or allergic or intolerant to any foods. Participants completed an initial pre-screening questionnaire where they reported their height, weight,



age, and gender. Self-reported BMI was calculated, and participants were selected on this basis to achieve an equal distribution of 'normal' ( $\text{BMI} < 25\text{kg/m}^2$ ), overweight ( $\text{BMI} = 25\pm 30\text{kg/m}^2$ ) and obese ( $\text{BMI} > 30\text{kg/m}^2$ ) groups. The sample comprised 35 'normal' weight, 31 overweight, and 22 participants with obesity. Once recruited, BMIs were re-classified based on height and weight measured in the laboratory. All participants gave informed consent. All received £30 (sterling) in remuneration for their assistance. The protocol was approved by the local Faculty of Science Human Research Ethics Committee.

### 3.3.2 *Food images*

To represent a range of energy densities, four foods were selected that are commonly consumed in the UK: McDonald's fries (3.0 kcal/g), four bean salad (1.1 kcal/g), chicken tikka (1.6kcal/g), and apple pie (2.9kcal/g). For each dish, a series of 50 images were photographed with portion sizes ranging from 20 kcal to 1000 kcal, in equal 20-kcal steps. The name of the food was included in the top-right corner of each photograph. All meals were photographed on an identical white plate (255-mm diameter). All images were taken using a high-resolution digital camera under the same lighting conditions.

### 3.3.3 *Measures*

The TFEQ, BMI, appetite, familiarity and liking measures were identical to Study 1 (Chapter 2). Participants completed liking and familiarity ratings for each of the test foods. A priori, it was decided to only include participants who were familiar with the test foods.

### 3.3.4 *IMI sensitivity task*

Two food images were presented on a VDU. One portion was presented on the left and labelled 'This meal for lunch'. A different plate of food was presented on the right and labelled 'This later meal'. Lunch was either a HED meal (McDonald's fries; MF) or a LED meal (four bean salad; FBS). The 'later meal' was either a fixed 400-kcal portion of chicken tikka masala with rice (CT) or apple pie (AP). Participants were asked to respond to the question 'How much would you eat for lunch RIGHT NOW if you had to eat all of the food on

the right for dinner ...[in time inserted].’ In an initial trial the IMI was ‘uncertain’ - participants were told to expect the meal anywhere between now and in 8 hours. Subsequently, participants completed eight of the trials where the IMI was certain; right now, 15 mins, 30 mins, 1 hour, 2 hours, 4 hours, or 8 hours. They were instructed that they would not be eating anything else in between the meals. Participants were instructed to use the arrow keys to adjust the size of the lunchtime portion and press the ‘Enter’ key when they had made their portion selection. Each participant completed a total of twenty-eight randomised trials; seven different IMIs repeated with four food combinations (MF&CT and FBS&CT; MF&AP and FBS&AP). This resulted in twenty-eight scores for each participant, reflecting the portion size chosen at each of the seven IMIs for the four food combinations. The orders of the meal timings and foods were randomised for each participant. Every trial started with a randomly selected portion size of the lunchtime food.

### *3.3.5 Post-task questions*

After completing the IMI sensitivity task, participants were asked about the strategies used to make portion decisions. In two separate questions, participants were asked to rate ‘the extent to which they considered potential future hunger/fullness in deciding how much food to select’ on a 100-mm visual-analogue scale

### *3.3.6 Delay monetary discounting-task*

The monetary delay discounting task was identical to Study 1 (Chapter 2).

## *3.4 Procedure*

Participants completed a lunchtime session between 11:00 and 14:00. On arrival, they reported how long ago they last ate and rated their appetite. They completed the IMI sensitivity task, followed by appetite, liking and familiarity ratings, and the monetary discounting task. Finally, participants completed the TFEQ and their height and weight was measured. Participants were debriefed and thanked for their assistance. Participants were

tested for approximately two hours as this experiment was run alongside other measures that addressed unrelated questions associated with food choice.

### 3.5 Data analysis

Due to a technical issue, liking and familiarity scores were not recorded for the apple pie. Therefore, it was decided that all sweet trials would be excluded from the analysis. To assess the extent to which participants discounted information about the certain meal timings, a measure of IMI sensitivity was derived. To calculate the gradient of change in portion size selection across time, two separate linear regressions were calculated for each participant, with portion sizes selected in the LED and HED food trials as the dependent variable and certain IMI (minutes) as the independent variable (c.f. Brunstrom et al., 2016). The regression equation was:  $\text{Portion size (kcal)} = \beta * \text{IMI (minutes)} + a$ . For each participant, this yielded two gradients and intercepts that relate HED and LED portion selection to IMI (certain IMI sensitivity score). Large, positive slopes were taken as evidence for greater sensitivity to information about the certain IMIs. Additionally, intercepts were used to determine the unique explanatory power of the slope term in later analysis.

To compare portion sizes selected in response to the certain vs. uncertain IMIs, the regression equation was used to predict how the portion sizes chosen in the uncertain condition correspond to a certain meal time. The aim was to predict the equivalent certain IMI that corresponded to the portion size selected when confronted with the uncertain IMI. The uncertain portion size (kcal) was inserted into the previously generated regression equation to predict the equivalent certain IMI:  $\text{certain IMI} = (\text{Uncertain portion size} - a) / \beta$ . The intention was to generate a certain IMI, which would infer whether the portion selected in response to the uncertain IMI resembled the portions selected at shorter or longer IMIs. However, the regression slopes were non-linear and variable for each participant, making it challenging to identify a regression equation that could accurately predict the uncertain IMI from the regression equations. As such, the certain and uncertain portion size selections could not be compared as intended. Instead, uncertain IMI sensitivity scores were calculated

following Study 1 (Chapter 2), by subtracting the average portion size selected at the certain IMIs from the portion size selected at the uncertain IMI. A separate uncertain IMI was calculated for the HED and LED foods. Correlations between uncertain IMI sensitivity with BMI and monetary delay discounting AUC were assessed.

Initially, a two-sided, paired samples t-test was used to assess whether certain IMI sensitivity differed between the HED and LED portions. If there was no evidence for a difference in certain IMI sensitivity, it was decided that composite intercepts and slopes would be used in the subsequent analysis. The composite certain IMI sensitivity scores were calculated by averaging the HED and LED IMI sensitivity scores (Composite IMI sensitivity = (HED IMI sensitivity + LED IMI sensitivity)/2). To explore the primary hypothesis, that progressively longer IMIs would result in larger portion selections, a planned t-test was performed to determine whether certain IMI sensitivity scores deviated significantly from zero. To assess whether participants selected larger portions in response to uncertainty, a repeated measures ANOVA was carried out to compare portion sizes selected at the uncertain, and average of the certain, IMIs.

Subsequently, IMI sensitivity, monetary discounting, and the interaction between certain IMI sensitivity and monetary discounting were assessed as predictors of BMI. Using multiple regression, composite certain IMI sensitivity scores and monetary discounting scores were entered simultaneously as independent predictors of BMI. To assess whether the effect of IMI sensitivity on BMI changes with monetary discounting, the interaction between monetary discounting and certain IMI sensitivity (IMI sensitivity scores \* monetary discounting AUC) was entered as an independent variable. Age, gender and TFEQ scores were also included in the regression analysis. To identify whether IMI sensitivity predicts variance in BMI independently of the average immediate portion size, each participant's intercept score was included in the regression analysis. The overall regression equation was:

$BMI = \beta_0 + \beta_1 * IMI \text{ Sensitivity} + \beta_2 * \text{Intercept} + \beta_3 * \text{Delay Discounting} + \beta_4 * (\text{Delay Discounting} * IMI \text{ sensitivity}) + \beta_5 * \text{Age} + \beta_6 * \text{Gender} + \beta_7 * \text{TFEQ-hunger} + \beta_8 * \text{TFEQ disinhibition}$

### 3.6 Results

#### 3.6.1 Participant characteristics

A small proportion of participants expressed unfamiliarity with the foods. Six participants who were unfamiliar with one food and two who were unfamiliar with two foods were excluded. The final sample of 80 participants (47 women, 32 men and 1 transgender) comprised 31 'normal', 29 overweight, and 20 participants with obesity. Table 3.1 shows participant characteristics.

Table 3.1. Means  $\pm$  SD for age, BMI, uncertain IMI sensitivity, certain IMI sensitivity (slope and intercept), monetary delay discounting AUC, TFEQ, liking and appetite.

Weight group	Measure	Mean $\pm$ SD
BMI < 25kg/m <sup>2</sup>	Age (y)	31.4 $\pm$ 11.0
	BMI (kg/m <sup>2</sup> )	22.2 $\pm$ 1.8
	Composite certain IMI sensitivity (Slope)	1.0 $\pm$ 0.6
	HED uncertain portion size (kcal)	729.7 $\pm$ 376.6
	LED uncertain portion size (kcal)	507.1 $\pm$ 265.6
	Intercept	291.8 $\pm$ 186.2
TFEQ	Restraint	7.3 $\pm$ 3.2
	Disinhibition	6.7 $\pm$ 2.7
	Hunger	6.4 $\pm$ 3.5
	Monetary Delay Discounting (AUC)	0.7 $\pm$ 0.2
Liking (0-100)	Chicken Tikka	81.4 $\pm$ 19.1
	McDonald's Fries	59.2 $\pm$ 24.4
	Four Bean Salad	65.0 $\pm$ 28.7

	Appetite (0-100)	Hunger	59.5 ± 27.8
		Fullness	42.4 ± 23.1
<hr/>			
	BMI = 25±30 kg/m <sup>2</sup>	Age (y)	32.9 ± 11.3
		BMI (kg/m <sup>2</sup> )	26.9 ± 1.6
		Composite certain IMI Sensitivity (Slope)	0.7 ± 0.4
		HED uncertain portion size (kcal)	660.7 ± 284.0
		LED uncertain portion size (kcal)	442.8 ± 208.7
		Intercept	276.9 ± 184.8
	TFEQ	Restraint	7.9 ± 4.2
		Disinhibition	8.6 ± 3.1
		Hunger	7.2 ± 3.8
		Monetary Delay Discounting (AUC)	0.6 ± 0.3
	Liking (0-100)	Chicken Tikka	77.8 ± 18.3
		McDonald's Fries	55.2 ± 31.8
		Four Bean Salad	49.2 ± 26.4
	Appetite (0-100)	Hunger	58.3 ± 24.6
		Fullness	52.6 ± 30.0
<hr/>			
	BMI > 30kg/m <sup>2</sup>	Age (y)	35.4 ± 12.0
		BMI (kg/m <sup>2</sup> )	37.3 ± 6.4
		Composite certain IMI Sensitivity (Slope)	0.5 ± 0.6
		HED uncertain portion size (kcal)	581.0 ± 197.8
		LED uncertain portion size (kcal)	341.0 ± 136.0
		Intercept	363.1 ± 214.6
	TFEQ	Restraint	9.5 ± 5.4
		Disinhibition	10.7 ± 2.9
		Hunger	9.2 ± 3.5
		Monetary Delay Discounting (AUC)	0.5 ± 0.3

Liking (0-100)	Chicken Tikka	77.7 ± 16.6
	McDonald's Fries	55.8 ± 30.1
	Four Bean Salad	66.9 ± 26.8
Appetite (0-100)	Hunger	55.1 ± 22.8
	Fullness	40.4 ± 25.2

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*N* = 31 'normal', 29 overweight, and 20 with obesity

### 3.6.2 Correlations

Hunger and fullness did not correlate with certain IMI sensitivity or uncertain IMI sensitivity (see Table 3.1 for mean hunger and fullness ratings). As there were no significant correlations between liking ratings of each test food with certain IMI sensitivity scores, uncertain portion size (See Table 3.2), liking was not included as a covariate in the regression analysis. As TFEQ-disinhibition and TFEQ-hunger correlated with BMI, these variables were included in the regression analysis. Pearson's correlations are reported in Table 3.2. A post-hoc power calculation based on the effect sizes from Study 1 (Chapter 2) showed a minimum of 45 participants would be required to detect a relationship between BMI, certain IMI sensitivity and monetary discounting with 95% power and  $\alpha = 0.05$ ; thus, the current study was powered to detect an effect.

### 3.6.3 Difference between HED and LED trials

There was no significant difference between certain IMI sensitivity in the HED ( $M = 0.32 \pm 0.25$ ) and LED trials ( $M = 0.33 \pm 0.28$ ),  $t(79) = -1.1$ ,  $p = 0.27$ , hence, certain IMI sensitivity scores were comparable. As such, the composite certain IMI sensitivity scores and intercept scores were used in the subsequent analyses. There was a significant difference between uncertain IMI sensitivity in the HED ( $M = 165.9 \pm 230.6$ ) and LED trials ( $M = 126.6 \pm 149.1$ ),  $t(79) = -6.5$ ,  $p = 0.001$ . Hence, the HED and LED uncertain IMI sensitivity scores were kept separate in the subsequent analyses. Both uncertain and certain composite IMI sensitivity scores were normally distributed, as assessed by Shapiro-Wilk's test ( $p > 0.05$ ) and there were no outliers in the data, as assessed by inspection of a boxplot.

### 3.6.4 Portion size across IMI

To assess whether the portion sizes significantly changed across IMI, we ran a t-test of certain IMI sensitivity scores (slope). Certain IMI sensitivity scores ( $M = 0.76 \pm 0.53$ ) were significantly different from zero,  $t(79) = 12.77$ ,  $p = 0.00$ . This demonstrates that portion selection was influenced by the length of the certain IMI (See Figure 3.1). Additionally, there was no significant difference between average portion sizes selected in response to the certain IMIs, compared to the uncertain IMI,  $F(1,71) = 3.2$ ,  $p = 0.09$ .

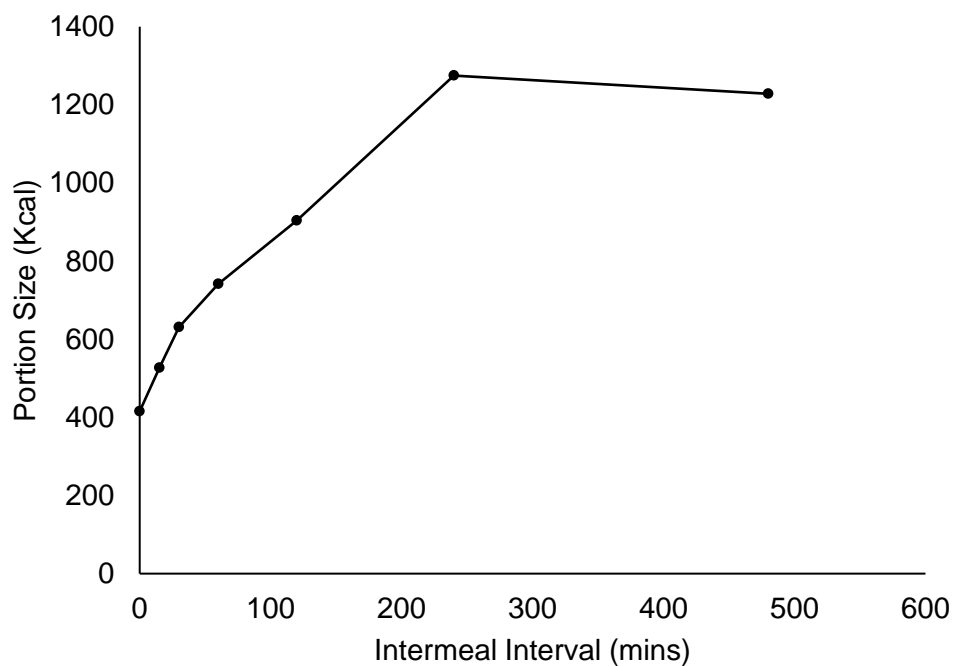


Figure 3.1. Mean portion size (kcal) selected in response to increasing IMIs.



Table 3.2. Pearson's correlations between certain IMI sensitivity (slope and intercept), uncertain IMI portion size, monetary delay discounting AUC, BMI, TFEQ (three subscales), hunger, fullness and liking.

	2	3	4	5	6	7	8	9	10	11	12	13	14
1. BMI	-0.30**	0.16	-0.11	-.26*	-.28*	.47**	0.04	.29**	-0.03	-0.12	-0.02	0.09	0.02
2. Composite IMI Sensitivity (slope)		-.33**	.35**	0.13	.31**	-0.12	-0.04	-0.1	0.16	-0.11	0.08	0.18	-0.04
3. Intercept			.40**	.54**	.55**	0.25*	-0.12	.24*	0.06	-0.17	0.19	0.2	0.2
4. Uncertain IMI Portion Size (McDonald's Fries, kcal)				.37**	-0.05	0.12	-0.17	0.11	0.2	-0.22	0.08	-0.05	.28*
5. Uncertain IMI Portion Size (Four Bean Salad, kcal)					0.23*	0.02	-0.01	-0.07	0.11	-0.07	0.16	0.27	0.06
6. Monetary Delay Discounting						0.01	0.02	0.1	0.04	0.04	0.18	-0.18	0.18
7. TFEQ-Disinhibition							0.04	.64**	0.12	-0.06	-0.03	0.21	-0.05
8. TFEQ-Restraint								0.08	-0.13	0.02	0.11	-0.07	0.03
9. TFEQ-Hunger									0.12	-0.14	0.02	0.2	0.02
10. Hunger										-.53**	0.13	-0.11	-0.01
11. Fullness											-.26*	0.0	0.14
12. Liking (Chicken Tikka)												0.0	-0.13

13. Liking (McDonald's Fries)

-0.14

14. Liking (Four Bean Salad)

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\*  $p < 0.05$  \*\*  $p < 0.01$

### 3.6.5 IMI sensitivity and monetary discounting as predictors of BMI

A multiple linear regression was run to assess the association between IMI sensitivity and monetary discounting with BMI. Certain IMI sensitivity negatively predicted variance in BMI,  $\beta = -3.49$ ,  $p = 0.02$ , indicating that those with a high BMI were less sensitive to information about IMIs (Figure 3.2). Intercept scores did not significantly predict BMI, suggesting that IMI sensitivity accounts for variance in BMI beyond the average immediate portion size ( $p > 0.05$ ). Monetary discounting predicted variance in BMI,  $\beta = -8.1$ ,  $p = 0.003$ . Those with a high BMI showed a greater tendency to discount monetary rewards. The interaction between IMI sensitivity and monetary discounting did not significantly predict variance in BMI,  $\beta = 2.9$ ,  $p = 0.46$ . This suggests monetary discounting and IMI sensitivity are separate constructs, which both predict BMI independently. Age, gender, TFEQ-hunger did not predict BMI (all  $p > 0.05$ , see Table 3.3). TFEQ-disinhibition significantly predicted BMI,  $\beta = 0.89$ ,  $p = 0.00$ . Separate regression coefficients with  $R^2$  values derived from multiple regression analysis are provided in Table 3.3.

Table 3.3. Regression coefficients with r-squared values derived from the multiple regression analysis.

Independent variable (IV)	$\beta$	$R^2$	$p$
Composite IMI sensitivity	-3.49	0.34	0.02
Composite intercept	0.00	0.34	0.83
Monetary delay discounting	-8.10	0.34	0.003
Delay discounting*IMI sensitivity	2.91	0.34	0.46
Age	0.05	0.34	0.44
Gender	-0.51	0.34	0.52
TFEQ-hunger	0.11	0.34	0.64
TFEQ-disinhibition	0.89	0.34	0.002

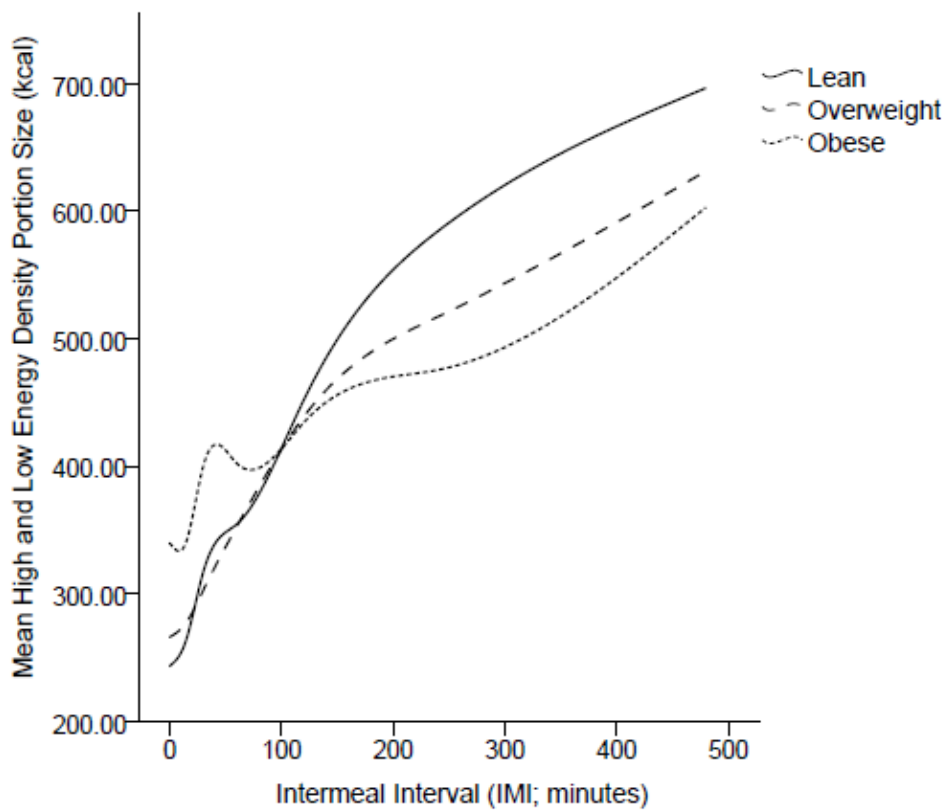


Figure 3.2. Mean composite (average of HED and LED) portion size (kcal) selected in response to increasing IMIs in lean ( $n = 31$ ), overweight ( $n = 29$ ) and obese ( $n = 20$ ) participants. Shallow slopes represent reduced sensitivity to IMIs. Curves were fitted to the mean composite portion sizes selected in response to IMIs; right now, 15 minutes, thirty minutes, one hour, two hours, four hours and eight hours. The graph is separated by BMI group for illustrative purposes, BMI was used as a continuous measure in the analysis.

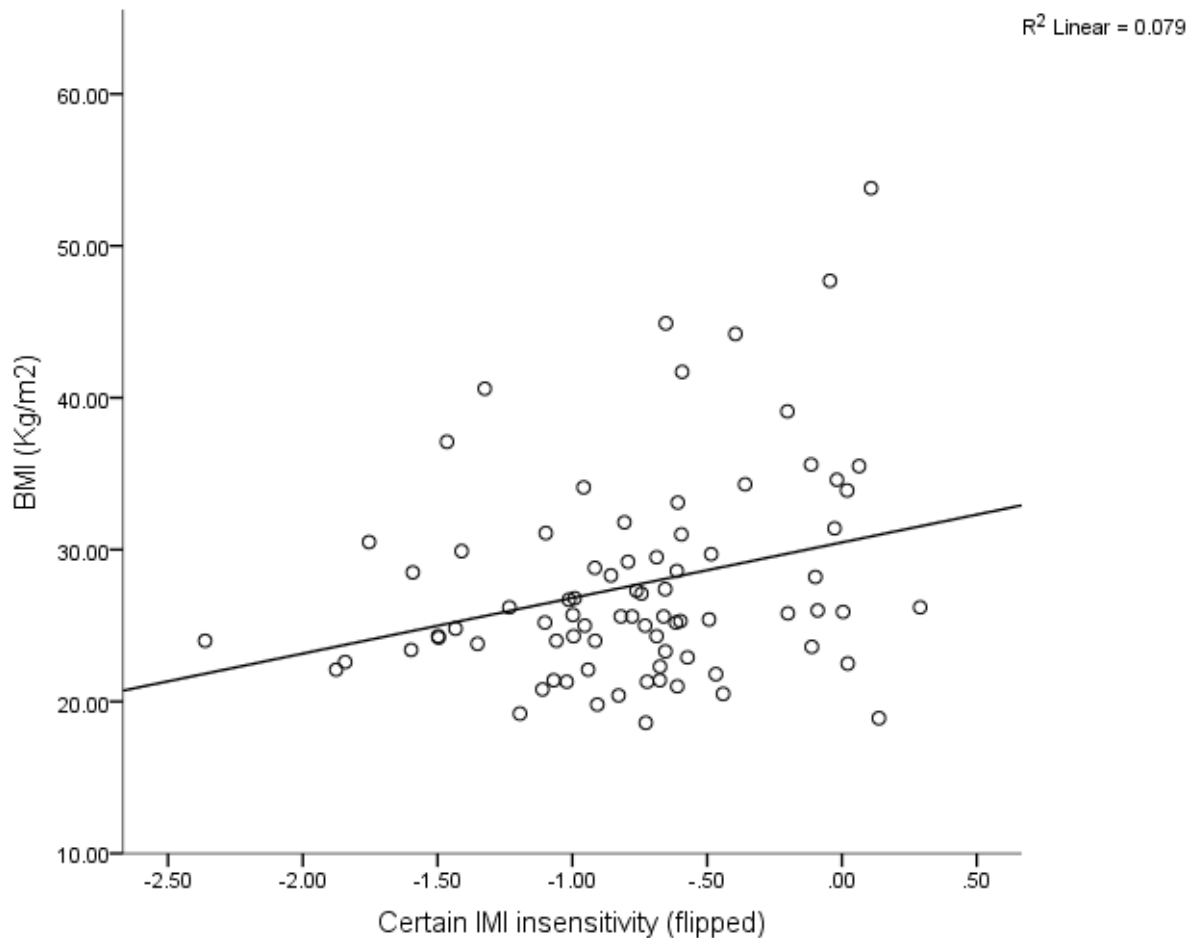


Figure 3.3. Correlation between BMI and uncertain IMI sensitivity. For visual depiction of the relationship, IMI sensitivity have been flipped to depict IMI insensitivity, as smaller scores reflect greater insensitivity. Each point represents a single participant. The line represents a best linear fit

### 3.6.6 Correlations between monetary delay discounting, BMI and portion size in response to an uncertain IMI

In the uncertain trials, portion selection of the HED food did not correlate with BMI,  $r = -0.11$ ,  $p = 0.35$ , or delay discounting,  $r = -0.05$ ,  $p = 0.69$ . Portion selection of the LED food did correlate with both BMI,  $r = -0.26$ ,  $p = 0.02$ , and delay discounting,  $r = 0.23$ ,  $p = 0.04$ .

### 3.6.7 *Self-reported concerns about fullness and hunger*

Concerns about hunger or fullness did not correlate with IMI sensitivity; hunger concern:  $r = 0.07$ ,  $p = 0.54$ , fullness concern:  $r = 0.13$ ,  $p = 0.25$ .

## 3.7 *Discussion*

This is the first study to show that information about future meal timings influences portion-size selection in participants with a wide BMI range. Consistent with the primary hypothesis, results show that participants selected larger portion sizes in response to a longer IMI. This confirms previous results from Study 1 (Chapter 2), suggesting that people use information about future meal timings to make decisions about portion size. In addition, these findings demonstrate that participants were equally sensitive to the length of an IMI when making portion-decisions about the HED food compared to the LED food.

These results have implications for the assessment of temporal discounting in eating behaviour. Dietary discounting tasks neglect to assess how future meal planning might influence discounting. In these tasks, the timings of subsequent meals are not controlled (Hendrickson & Rasmussen, 2013; Manwaring et al., 2011; Rasmussen et al., 2010; Schiff et al., 2016). The findings suggest that dietary decisions are influenced by the length of an IMI. It is important that dietary discounting studies account for the fact that the value of food is not stable and is influenced by future meal planning. This distinction is subtle, yet potentially essential, and is generally overlooked in studies exploring the acute effects of discounting on eating behaviour.

In line with the second hypotheses, and consistent with findings from Study 1 (Chapter 2), high BMI was negatively associated with sensitivity to the length of an IMI. These results indicate that people differ in their capacity to consider the future when making dietary decisions. Specifically, individuals with a high BMI discounted information about the length of the IMI. Furthermore, those with a high BMI showed reduced IMI sensitivity in portion decisions about both HED and LED foods. It is possible that they are more concerned with how much they want to eat in the moment and discount information about

future meal timings. Indeed, obesity has been related to poor future episodic thinking about food (Daniel et al., 2013). In contrast, lean individuals were more sensitive to information about the length of the IMI. This suggests they are more future-oriented and plan for potential meal times. However, the tendency to discount hunger and fullness was not evident in self-report questions. This suggests that participants were unaware they discounted information about the IMI length.

There was a negative correlation between high BMI and steep monetary delay discounting with reduced IMI sensitivity with LED, but not HED foods. This suggests that non-future oriented individuals, and those with a high BMI, selected smaller portions when confronted with the uncertain condition. This partially supports findings from Study 1 (Chapter 2) and improves confidence in the hypothesis that impulsive and overweight individuals are less concerned about the prospect of an uncertain IMI. However, only portion size selection of the LED food in the uncertain IMI was significantly related to BMI and monetary discounting, which differs from the findings of Study 1 (Chapter 2). One explanation as to why these associations were not observed with HED foods is because the food may have had a higher reward value. Highly rewarding food could have caused all participants to discount the future, negating any differences between steep and shallow discounters. In contrast, the LED food with a lower reward value may have allowed differences in trait delay discounting to be teased apart, causing non-future oriented individuals, and those with higher BMIs, to be less sensitive to the prospect of an uncertain IMI.

One possibility is that individuals with a high BMI discounted the length and certainty of an IMI because they are less sensitive to signals of hunger and fullness. BMI has been linked to reduced interoceptive awareness (Herbert et al., 2013) and poor sensitivity to hunger and satiety cues (Herbert & Pollatos, 2014; Stunkard., 1959). It is hypothesized that visceral signals of hunger and fullness may have less effect on portion size decisions for individuals with obesity. In this study, participants with a high BMI may have been less

sensitive to the change in meal timing because they did not anticipate feeling hungry during the IMI. However, contrasting findings show that obese and lean people do not differ in their sensitivity to gastric filling (Geliebter, Westreich, & Gage, 1988). At present, this alternative account cannot be ruled out; research is required to assess whether IMI sensitivity is associated with individual differences in interoception.

The current results may help to inform our understanding of meal patterns and the development of interventions for obesity. Structured meal timings are regarded as an effective tool for weight loss (Farshchi et al., 2005b; Kruger, Blanck, & Gillespie, 2006). However, patients with a high BMI often struggle to maintain diets and meal plans (Aggarwal, Liao, Allegrante, & Mosca, 2010; Pijls, de Vries, van Eijk, & Donker, 2000; Thuan & Avignon, 2005), with lower attrition rates in individuals with a high BMI. These current findings suggest that individuals with a high BMI are less sensitive to certain meal timings. This might help to explain why individuals with a high BMI be less responsive to meal plans; if information about future meal timings is discounted, people may eat smaller portions and become hungrier sooner. This could lead them to diverge from their meal plan by snacking, eating more or choosing higher energy dense foods at the next meal. Indeed, greater monetary discounting in obese participants predicts reduced success at following weight-loss interventions (Weygandt et al., 2015). This supports the notion that an individual's reduced sensitivity to meal timings might affect their ability to follow and maintain a structured eating routine. One possibility is that individuals attempting meal-planning interventions might benefit from training in their ability to forward think. For example, studies have employed episodic future thinking tasks to reduce discounting and, consequentially, reduce food intake and snacking in obese individuals (Daniel et al., 2013; Dassen, Jansen, Nederkoorn, & Houben, 2016). The current findings might contribute to a novel intervention that promotes future-thinking about meal timings, to help patients successfully adhere to structured meal patterns.



Contrary to the hypothesis, there was no interaction between monetary discounting and reduced IMI sensitivity, yet both significantly predicted BMI. This suggests that monetary discounting and IMI discounting have independent effects on eating behaviour, and consequential weight gain. It is proposed that the monetary task reflects a tendency to discount long-term events. These results suggest that long-term discounting should be considered separate from shorter-term discounting between meals. This is a critical distinction for future research, reinforcing the notion that there is no single underlying temporal-discounting process (Green & Myerson, 2013). It is important that future studies consider this division and begin to move away from a solely long-term discounting model to understand the role of dietary discounting in eating behaviours related to obesity.

Although computer-based portion judgments are predictive of real food intake (Pouyet et al., 2015; Taylor et al., 2014), it could be instructive to explore how temporal discounting moderates real food intake at varying IMI lengths. One possible issue is that obese and overweight individuals are shown to under-report portion sizes (Johansson, Wikman, Åhrén, & Johansson, 2001; Okubo & Sasaki, 2004). However, the data in this study should not be affected by underreporting as they reflect the rate of change in portion size across time. An additional limitation is that the regression equations for the certain IMIs did not allow a certain IMI to be predicted from uncertain portion size selections, making it difficult to conclude whether uncertain IMIs drives the selection of 'larger than normal' portion sizes during the IMI. Future research is required to test this hypothesis. In addition, trials involving sweet foods were excluded. Future replications could assess whether portion size selection in response to IMIs differs with sweet and savoury foods. Finally, as the aims of the computerised IMI task were not concealed from the participants, it is likely that the task was subject to demand characteristics in which participants performance was influenced by their understanding of the study aims. This should be remedied in the next chapter by assessing the effects of real IMIs on food intake, and concealing the study aims from the participants.

### 3.8 *Chapter summary*

The findings support those from Study 1 (Chapter 2), that information about the length of an IMI influences portion size judgements and that individuals with a high BMI are less sensitive to this information. These observations might help to explain associations between obesity and irregular meal timings and/or snacking behaviour, which in turn might form the basis for a targeted intervention that promotes future thinking in meal planning. Future research is required to confirm whether these findings generalise to actual food intake.

### 3.9 *Acknowledgments*

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## 4 Chapter 4. Studies 3, 4 and 5.

### “How long until lunch?” The effects of manipulating lunch timings on food intake at breakfast

The author was solely responsible for the design, implementation, participant recruitment, analysis, interpretation and write up of the data reported below. Jeff Brunstrom supervised this study.

#### 4.1 Chapter Summary

Findings from Chapter 2 and 3 showed that the length of an IMI influences computerised portion size selection. Thus, decisions about how much to eat are made prior to the meal and are significantly affected by future meal planning. It was proposed that information about future meal timings allows individuals to prepare for future hunger or fullness during the IMI. The primary aim of this chapter was to determine whether these conclusions extend to real food intake. In three experiments, the effects of the length and certainty of an IMI on breakfast intake were assessed. An additional aim was to explore *why* information about the length of a future IMI influences portion size. Study 4 and 5 tested the effects of a long vs. short IMI on food reward, predicted hunger and expected satiety.

The key aims are:

4. To replicate the findings reported in Chapter 2 and 3, that participants would choose larger portion sizes when confronted with a longer IMI, with real food and genuine IMIs.
5. To assess whether an uncertain IMI significantly affects real food intake
6. Unpick explanations as to why a longer IMI drives greater portion size selection, by assessing the influence of a long and short IMI on food reward, expected satiety, and predicted future hunger.

## 4.2 Introduction

One of the key aims addressed in this thesis is to determine whether information about future meal timings influences decisions about how much food to eat. The results from Chapter 2 and 3 support this hypothesis; participants selected larger computerised portions in response to a longer IMI. However, these experiments have only tested the hypothesis using computerised portion size selection tasks. Computerised portion size judgements are limited in their generalisability to real-world eating behaviour; hence the conclusions lack external validity. To test the validity of the finding that information about the length of an IMI drives portion selection, the methods from Chapter 2 were replicated with real food and the length and certainty of genuine IMIs was manipulated.

The ability to engage in meal planning is contingent on meal timings being predictable. In the real world, the specific times at which people eat are not always planned, which can generate uncertainty about the length of an IMI. It is important to understand how real-world meal planning, or lack thereof, influences portion size decisions. Thus, an additional aim, addressed in Study 1 (Chapter 2), was to understand how uncertainty about future meal timings influences portion size. It was predicted that when IMIs are certain, individuals can make portion size decisions that take account of future hunger or expected satiety. Conversely, when an IMI is uncertain, planning may be compromised. In Study 1, participants made computerized portion size decisions in response to a certain short, certain long and uncertain IMI. Results demonstrated that individuals differed in their sensitivity to information about uncertain IMIs; individuals with a high BMI and higher monetary discounting selected smaller portions in response to uncertain meal timings. However, there was little evidence to support the prediction that people would select larger portions when confronted with an uncertain IMI, compared to the certain IMIs. One explanation is that the computer task did not generate genuine uncertainty. In the IMI task used in Study 1 (Chapter 2), the uncertain IMI was hypothetical, meaning that participants might not have been truly uncertain about the IMI. Further testing in which participants are genuinely uncertain about

the length of an IMI is required to explore whether uncertainty about the length of an IMI affects portion size decisions. The following three studies are pilot experiments. Study 3 was designed to assess whether people choose to eat more food when confronted with an IMI that is genuinely uncertain. The methods from the IMI computer task used in Chapter 2 were replicated in a laboratory experiment. The length and certainty of a real IMI was manipulated, and food intake was assessed.

An additional aim of this chapter was to assess the external validity of the computerised IMI task, by establishing whether the measure can be generalised to real-world behaviours. As investigating the effects of a real IMI on food intake is laborious and time intensive, it is important to ensure that the computerised IMI task validly measures how people make portion size decisions in response to real IMIs. Study 4 assessed whether sensitivity to certain and uncertain IMIs derived from the computer task were reflective of sensitivity to real-life IMIs. It was predicted that the uncertain IMI sensitivity (difference between portion size selected in the uncertain IMI and an average of the portion sizes selected in the certain IMIs) and certain IMI sensitivity (difference between portion sizes at the long and short IMI) would be equivalent in the computer and 'real' food intake tasks. Finally, this chapter aimed to explore and test possible underlying explanations as to why IMI influences food intake. Studies 4 and 5 were exploratory, designed to isolate factors that drive people to eat more when confronted with a longer IMI. These hypotheses will be outlined in more detail in Studies 4 and 5.

The central aim of Study 3 was to assess the effects of the length and certainty of a real IMI on food intake. The methods from Chapter 2 were replicated by systematically manipulating a real IMI. However, the computerised task in Chapter 2 assessed lunch portion size decisions in response to the IMI before dinner (5pm, 9pm, 5pm or 9pm). Due to University opening times, it was more appropriate to test the IMI between breakfast and lunchtime. Breakfast intake was measured in response to the IMI before lunch (11am, 2pm

and 11am or 2pm). Participants selected how much food to eat at breakfast in response to a short, long and uncertain lunchtime.

First, following the results from Chapter 2 and 3, it was predicted that participants would select larger portions in response to a longer IMI. Second, it was hypothesised that participants would select larger portions when confronted with a genuine uncertain IMI, compared to the certain IMIs. Third, Study 3 was designed to assess the external validity of the IMI computerised task by comparing the computerised and 'real' food intake tasks. It was predicted that the computerised uncertain and certain IMI sensitivity scores would be highly correlated with the equivalent scores from 'real' portion size decisions. In addition, demographic information, such as BMI, as well as liking and familiarity with the test foods was assessed.

### **4.3 Study 3**

#### *4.3.1 Methods – Study 3*

##### *4.3.1.1 Participants*

Participants (N = 29, 21 women and 8 men) were healthy undergraduate and postgraduate students at the University of Bristol, recruited through the laboratory volunteer database, poster advertisements, and by word of mouth. They were asked to contact the research co-ordinator for further details of the study if they were interested in taking part. To reduce demand awareness, participants were told that the purpose of the study was to explore 'the effects of breakfast and lunch on memory'. Participants were excluded if they were vegetarian or vegan, not fluent in English, taking any medication that might influence appetite or metabolism (with the exception of oral contraceptive pills), or allergic or intolerant to any foods. On completion of the study, participants received £10 (Sterling) in remuneration for their assistance or were reimbursed with course credits. Participants had an average age of 26 years and average BMI of 23.3kg/m<sup>2</sup>. The protocol was approved by the local Faculty of Science Human Research Ethics Committee.

#### 4.3.1.2 *Food images*

Breakfast and lunch food were selected that are commonly consumed as main meals in the UK: a choice of Cheerios or Cocopops cereal for breakfast and cheese and tomato pizza for lunch. For each food, a series of 50 photographs were taken with portion sizes ranging from 20 kcal to 1000 kcal, in equal 20 kcal steps. The images were taken using a high-resolution digital camera under identical lighting conditions. The pizza was photographed on the same white plate (255-mm diameter). The cereals were photographed in a 2L glass bowl with a 500ml jug for milk.

#### 4.3.1.3 *Measures*

Measures of BMI, liking and familiarity were identical to those used in Chapter 2. Participants completed liking and familiarity ratings for the breakfast cereals (Cocopops and Cheerios) and pizza.

#### 4.3.1.4 *Computerised breakfast and lunch IMI tasks*

Two versions of the computer task were included in the study. The first was identical to the lunch IMI task described in Chapter 2. Participants were required to select the portion size of a lunchtime meal of curry and rice, with the information that they would be eating a fixed 400 kcal portion of spaghetti bolognese for dinner at 5pm (short IMI), 9pm (long IMI), and either 5pm or 9pm (uncertain IMI). The second was a breakfast version of the computerised IMI task, included to ensure that the 'real' and computer tasks were directly comparable. The same foods and meal timings used in the real task were mirrored in this computer task. In this version, participants were asked to select a breakfast portion of Cheerios cereal with milk in response to information that they would be eating a fixed portion of 400 kcal of cheese and tomato pizza at lunchtime. To mirror the real IMI timings, participants were told expect their lunchtime meal at 11am (short IMI), 2pm (long IMI) and either 11am or 2pm (uncertain IMI). The order of the trials was randomised across participants and each trial started with a randomly selected portion size of the food. For both

the lunch and breakfast versions of the task, portion size (kcal) was recorded in response to each IMI.

#### *4.3.1.5 Procedure*

In this within-subjects study, all participants attended the lab on three days. On each day, they attended sessions at both breakfast and lunch. All participants took part in three conditions; a short-certain IMI where participants are told they will receive lunch at 11am; a long-certain IMI where participants are told they will receive lunch at 2pm; an uncertain IMI where participants are told they will receive lunch at either 11am or 2pm. The aims of the study were concealed by informing participants that the study was designed to test the effects of breakfast and lunch intake on memory. Participants were given a list of words to learn in each breakfast session and asked to complete a bogus memory test when they came back in for lunch.

In the first session, participants were given a choice between Cheerios and Cocopops for breakfast and were informed that they had to eat the same cereal in each session. A choice was given to ensure that participants did not strongly dislike the cereal, which would influence the amount of food they ate. In all conditions, participants arrived for the breakfast session at 9.00am and completed appetite, fullness and liking measures. Prior to eating breakfast, participants were shown a photograph of the exact portion of pizza they will receive for lunch and instructed that they 'will have to eat the entire portion'. The experimenter told participants what time their lunch would be. In the uncertain condition, the experimenter deceived the participants by telling them "I'm very sorry but there was a mix up with the schedule for the laboratory and someone else might be using the room. I'm not sure what time the room is available for use, you will either have to come in for lunch at 11am or 2pm." Subsequently, participants were given a 2L Tupperware of cereal (600g) and jug of 500ml milk with a 2L glass bowl. They were instructed to eat how much they would like and given 20 mins to eat. Both cereal and milk were weighed before and after eating to calculate total food intake. Participants in the uncertain condition were told that their lunch would be at



either at 11am or 2pm after they had finished breakfast. The lunch timing in the uncertain condition was counterbalanced across participants. After eating breakfast, participants were given 5 minutes to memorise a list of words as part of the bogus memory task to conceal the study aims.

In the lunchtime session, participants were served 400 kcal of pizza and reminded to finish everything on the plate. After 15 minutes participants were instructed to stop eating. All participants ate the entire portion of pizza in each condition. After lunch, participants were given three minutes to write down as many words as they could remember as possible as part of the bogus memory task. In the final lunchtime session that was attended, participants were required to complete a series of additional measures. First, participants carried out the computerized breakfast and lunch IMI tasks. Finally, participants' height and weight was measured to calculate BMI and participants were asked to guess the study aim and hypothesis. Participants were then debriefed, compensated for their time and thanked for their assistance. On each day, participants were in the lab for 25 minutes at breakfast and 20 minutes at lunch except for the final lunchtime session, which lasted approximately 30 minutes.

#### *4.3.1.6 Data analysis*

Total food intake (calories of cereal + milk) was calculated for each IMI condition. Uncertain IMI sensitivity was calculated following methods used in Chapter 2: uncertain IMI sensitivity score =  $\frac{\text{uncertain portion size} - (\text{short-certain portion size} + \text{long-certain portion size})}{2}$ . This provides a measure of the effect of uncertainty, relative to certainty, on food intake. A separate uncertain IMI sensitivity score was calculated for each participant. A high score indicates that larger portions were chosen in the uncertain condition than in the average of the two portions selected in the certain conditions. A separate certain IMI sensitivity score was also calculated for each participant: Certain IMI sensitivity =  $\frac{\text{long IMI portion size} - \text{short IMI portion size}}{2}$ . A high certain IMI sensitivity score indicates a greater adjustment in portion size in response to the long, compared to short, IMI. Both uncertain

and certain IMI sensitivity scores were calculated for all three tasks ('real' breakfast intake, computerised breakfast portion size and computerised lunchtime portion size), resulting in a total of 6 scores (3 certain IMI sensitivity scores and 3 uncertain IMI sensitivity scores).

First, to test the hypothesis that the length of an IMI would influence food intake, a paired-samples t-test was conducted to compare food intake (kcal) at the long and short IMIs. Second, to test the hypothesis that participants would eat more in response to an uncertain IMI, compared to the certain IMIs, a one-way t-test was conducted to assess whether uncertain IMI sensitivity scores deviated significantly from one. The effect size from this result was used to make a power calculation for the sample size required to show an effect of uncertainty on food intake in a future study. Third, to evaluate the external validity of the computerised IMI task, Pearson's correlations were assessed between the real and computerised uncertain and certain IMI sensitivity scores. It was predicted that both the IMI sensitivity scores from the computerised breakfast and lunch IMI tasks would correlate with the IMI sensitivity scores from the 'real' IMI task.

#### *4.3.2 Results*

##### *4.3.2.1 Participants*

Three participants dropped out on the third session of the experiment, so were excluded from analyses. This resulted in a total of 26 participants (19 women and 7 men) with an average age of 24 years and average BMI of 23kg/m<sup>2</sup>. All participants were familiar with all test foods. Of the 26 participants, only 2 correctly guessed the study aim.

##### *4.3.2.2 Effect of IMI length on food intake*

There was a significant difference (74.9 kcal) between breakfast intake in response to the long and short IMI,  $t(25) = -3.76$ ,  $p = 0.001$ . Participants ate more food when confronted with a long IMI ( $M = 266.8 \pm 113.3$  kcal), compared to the short IMI ( $M = 192.0 \pm 67.5$  kcal). There was little evidence for a correlation between food intake and liking, hunger

or fullness at each IMI. See Figure 4.1 for average portion size at each IMI from the 'real' and computerised tasks.

#### 4.3.2.3 Effect of IMI certainty on food intake

Uncertain IMI sensitivity for real food intake did not significantly deviate from one  $t(25) = 2.8, p = .78$ . Participants ate a similar amount in the uncertain condition ( $M = 235.2 \pm 83.2$  kcal) as the average of the two certain conditions ( $M = 234.46 \pm 75.32$  kcal). The effect size calculation showed that a sample size of 14162 would be required to detect an effect with an  $\alpha$  of 0.05 and a  $1-\beta$  of 0.80. This suggests that the effect of uncertainty about the IMI on portion size selection is minimal.

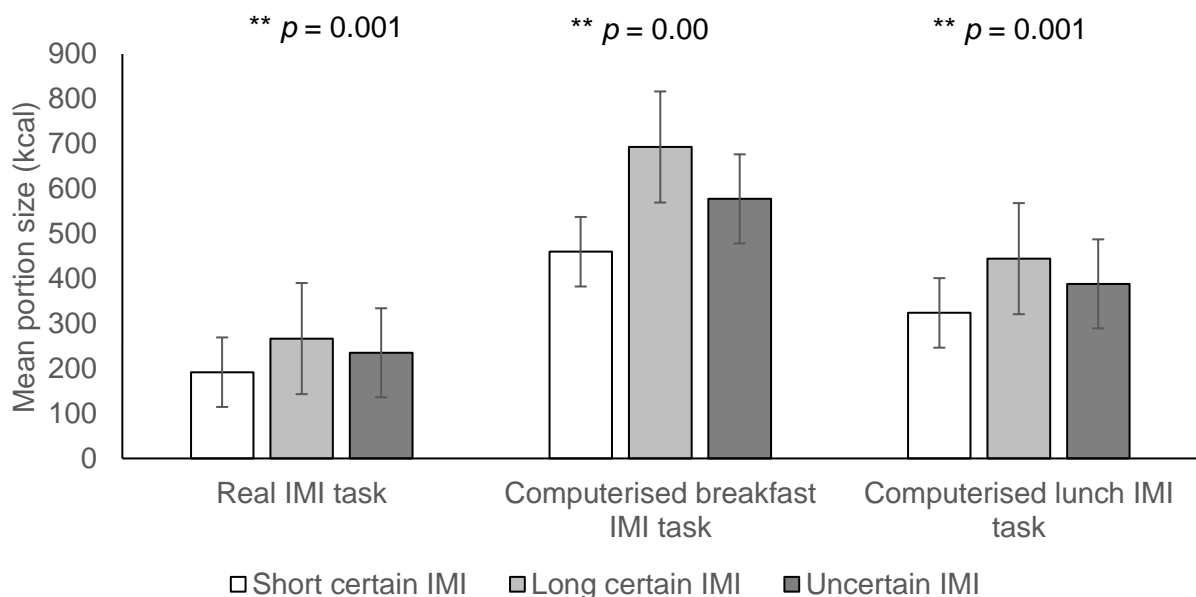


Figure 4.1. Means for food intake or computerised portion size selection in response to a real/computerised short IMI, long IMI, and uncertain IMI ( $N = 26$ ).  $P$ -values reflect pairwise comparisons of food intake at the long compared to short certain IMIs in each task. In every task, the differences between portion selection in the uncertain IMI condition did not significantly differ from the average of the two certain conditions.

#### 4.3.2.4 Comparison between real food intake and computerised IMI tasks

There was little evidence for a correlation between uncertain IMI sensitivity scores from the real food task and the computerised breakfast task,  $r = -0.20, p = 0.32$ . Similarly,

there was little evidence for a correlation between certain IMI sensitivity scores from the real food task and computerised breakfast task,  $r = 0.01$ ,  $p = 0.95$ . There was evidence for a significant correlation between uncertain IMI sensitivity from the real food and computerised lunch task,  $r = 0.44$ ,  $p = 0.02$ , but no significant correlation between certain IMI sensitivity scores,  $r = -0.35$ ,  $p = 0.08$ . See Table 4.1 for mean food intake in each condition of the three IMI tasks.

Table 4.1. Mean portion sizes and standard deviations in the real food intake task, computer breakfast IMI task, computer lunch IMI task ( $N = 26$ ).

	Mean (kcal) short IMI $\pm$ SD	Mean (kcal) long IMI $\pm$ SD	Mean (kcal) uncertain IMI $\pm$ SD
Food intake	191.96 $\pm$ 67.5	266.78 $\pm$ 113.3	235.15 $\pm$ 83.2
Computer breakfast portion size	460.00 $\pm$ 260.2	693.08 $\pm$ 214.4	577.69 $\pm$ 213.5
Computer lunch portion size	323.9 $\pm$ 134.6	444.6 $\pm$ 160.4	388.5 $\pm$ 167.9

### 4.3.3 Interim discussion

Findings from Study 3 support the first hypothesis, that individuals would eat more food when confronted with a longer IMI. This reinforces the external validity of the findings reported in Studies 1 and 2 (Chapter 2 and 3) that the length of an IMI influences portion size selection. The effects of a certain IMI on food intake will be explored in more detail in the subsequent two studies. Evidence did not support the second hypothesis that people would eat more food in response to an uncertain, compared to certain, IMI. In line with Study 1 (Chapter 2), findings showed that portion size in response to an uncertain IMI was not significantly different from the average portion size selected in response to the certain IMIs. These results suggest that uncertainty about future meal timings does not lead to greater food intake. Given that the power calculation revealed that an extremely large sample size

( $N = 14162$ ) would be required to detect a significant effect, this hypothesis was not tested in the follow-up studies.

The third aim was to test the external validity of the computerised IMI tasks. Uncertain IMI sensitivity scores derived from the computerised lunch task significantly correlated with scores derived from the real breakfast task. This suggests that the computerised lunch IMI task used in Study 1 (Chapter 2) might be a valid measure of uncertain IMI sensitivity. However, there was no significant correlation between the certain IMI sensitivity scores derived from the real and computerised lunchtime IMI tasks. Further research with a larger sample size is required to substantiate these preliminary findings and determine the external validity of the IMI task.

Conversely, there were no significant correlations between real and computerised breakfast IMI sensitivity scores. The computerised breakfast task had several methodological limitations that might explain why real food intake did not correlate with computerised breakfast portion selection. One critical issue was that the same food was not directly compared in the real food intake and computerised breakfast task. Participants were given a choice between Cheerios and Cocopops for their real breakfast meal. However, in the computerised version of the breakfast task, all participants were asked to select the amount of Cheerios they would like to eat. Therefore, food intake for participants who selected Cocopops ( $N = 11$ ) could not be reliably compared with computerised portion selection of Cheerios. Due to this error, and the relatively small sample size, it is unsurprising that there was no association between portion sizes selected at breakfast in the real and computerised tasks.

In addition, the size of the bowl used in both the computerised and real breakfast intake tasks may have been an issue. Participants were served breakfast in a 2L bowl to ensure that they would be able to select as large a portion as they desired. Participants were given a large bowl to encourage them to eat an amount that they thought would starve of hunger or prevent fullness in the IMI, rather than selecting portions based on judgements of

a 'normal' breakfast portion. To ensure the real and computerised tasks were consistent, the same 2L bowl was used in the photographs of cereal shown to participants in the computerised portions size task. However, participants tended to select significantly larger portion sizes in the computerised breakfast task (mean computerised portion size = 577 kcal, whereas mean real breakfast intake = 231 kcal). The use of an unusual 2L bowl may have mislead participants, causing them to underestimate the number of calories in the images of the cereals. This problem could be easily remedied by providing participants a normal cereal size bowl in both the computerised and real food intake tasks.

With these issues in mind, the weak correlations found between IMI sensitivity scores from the real and computerised breakfast tasks probably reflected these methodological limitations. As such, it is likely that IMI sensitivity scores from the real and computerised IMI tasks in this study cannot be reliably or accurately compared. Therefore, the generalizability of the computerised breakfast task to real food intake required further testing. The methods presented in Study 4 were designed to resolve these issues with Study 3, by ensuring the same standard-size cereal bowl and cereal type were used in both real and computerised versions of the task.

It is also important to consider the issue of measurement reliability and attenuation on the observed correlations between the IMI tasks. To estimate the true nature of the relationship between the measures, it is best practice to calculate the estimated correlation coefficients based on the reliability of the real and computerised measures. As these tasks are novel, reliability scores have not yet been established. Given that a reliability of 1 is highly unlikely for psychological measures, and a reliability higher than 0.8 shouldn't be assumed, a minimum acceptable reliability coefficient of 0.7 is estimated for the IMI tasks. Based on these reliability estimates, the corrected coefficient between the real and computerised breakfast uncertain IMI sensitivity scores is 0.29, and certain IMI sensitivity scores is 0.14. The corrected correlation between the real and lunchtime computerised tasks for uncertain IMI sensitivity scores is 0.63 and certain IMI sensitivity scores is 0.5. A post-hoc

power calculation reveals that with our sample size of 26, an  $\alpha$  of 0.05 and a  $1-\beta$  of 0.80, the observable correlation would have needed to be 0.45. Therefore, based on the reliabilities of the IMI measures, it was not possible to detect a correlation between the real and computerised breakfast tasks, and thus the non-significant findings reflect lack of power. However, testing a larger sample size was not possible in Study 4 and 5, as these were designed as pilot experiments to test proof-of concept. Future research should test the test-retest reliability of the IMI sensitivity measures in a larger sample size. As the expected observable correlations between the real and lunchtime computerised tasks are higher than the detectable correlation powered by the sample size, this suggest there was enough power to confirm these results.

#### **4.4 Study 4**

The results from Study 3 showed that food intake increased with the length of an IMI, replicating the findings from Studies 1 and 2 (Chapter 2 and 3) with real food intake. As this appears to be a robust phenomenon, shown with both computerised portion selection and real food intake, the subsequent experiments were designed to explore *why* people adjust their portion sizes with the length of an IMI. One potential explanation is that subjective hunger is influenced by the length of an IMI. It is possible that people experience greater hunger in response to a longer IMI, causing them to select larger portions. To investigate this hypothesis, self-reported hunger ratings, completed prior to eating breakfast, were compared in the long and short IMI. It was predicted that participants would report greater hunger in response to the long IMI. Furthermore, to assess whether change in hunger is driver of portion size selection, the difference in hunger ratings was explored as a predictor of the difference in food intake at the two IMIs.

An additional possibility is that a longer IMI increases the reward value of food, driving participants to eat more. The subjective value of food reward is thought to underpin the motivation to seek out and consume foods (Finlayson, King, & Blundell, 2007). The reward value of food is subject to change (Higgs, 2016). For example, liking and expected

satiety (Brunstrom & Shakeshaft, 2009; Rogers & Hardman, 2015) have been shown to predict food reward. One possibility is that food might also be more rewarding if an individual knows they are going longer without eating their next meal. This might explain why people eat more when confronted with a longer IMI; a long IMI could raise the reward value of food, in turn, motivating the selection of larger portion sizes. An aim of Study 4 was to test the hypothesis that food reward is influenced by future meal timings, and to determine whether a change in the subjective reward value of food explains why portion selection increases with a longer IMI.

There are multiple approaches to measuring food reward (Epstein, LeDy, Temple, & Faith, 2007). It has been argued (Berridge, 1996; Finlayson et al., 2007) that reward can be separated into distinct components - "liking" (pleasure) and "wanting" (motivation). To measure the wanting aspect of food reward, methods have been designed to measure the reinforcing value of food (Bickel, Marsch, & Carroll, 2000). This is defined as an individual's motivation to engage in a behaviour required to obtain stimulus. Food is a strong reinforcer, in that people will exert a considerable amount of effort to obtain it (Berridge, 1996; Salamone, 1994). Some paradigms assess the relative reinforcing value of food (RRV), by quantifying how much effort will be exerted to receive food, compared to a non-food reinforcer (Bickel et al., 2000; Epstein, Temple, et al., 2007; Saelens & Epstein, 1996; Temple, Legierski, Giacomelli, Salvy, & Epstein, 2008). Tasks used to measure the RRV of food typically present increasing schedules, in which the amount of effort required to obtain the food increases, while the amount of effort required to obtain the non-food reward stays constant (Lappalainen & Epstein, 1990). However, these tasks are often time intensive and only one participant can be tested at a time. To circumvent these issues, a task was developed (Goldfield, Epstein, Davidson, & Saad, 2005) that involves participants choosing between a food and non-food alternative. The amount of work required to obtain the non-food reward remains the same at each trial, while the amount of work required to obtain the food reward increases every trial. The RRV of the food is calculated by establishing the point of indifference, which signifies the maximum amount of effort a participant is prepared to



exert to obtain food. In Study 4, an adapted version of this task (Goldfield et al., 2005) was used to assess how the RRV of food changes with the length of an IMI.

Alternatively, rating measures have been designed to separately assess both the wanting and liking aspects of food reward (Rogers & Hardman, 2015). In this task, participants are asked to taste a small bite of a food and rate their desire to eat the remaining portion, as well as how pleasant the food is. The “desire to eat” rating is thought to represent the ‘wanting’ aspect of food reward, as individuals will have a stronger desire to eat a food that they perceive to have a higher reward value (Rogers & Hardman, 2015). The “pleasantness” rating is thought to represent the ‘liking’ aspect of food reward. Evidence has demonstrated that the “desire to eat measure”, is comparable, or even superior to traditional measures of food reward (e.g. willingness to pay; Rogers & Hardman, 2015). To assess how the length of an IMI influences food reward, an adapted version of the “desire to eat” task with specific breakfast foods was also included. In both reward tasks, it was predicted that the subjective reward value of food would be higher when confronted with a longer IMI. Furthermore, it was hypothesized that changes in the reward value of food could be driving portion selection in response to the length of an IMI.

In this study, a similar within-subjects study was conducted, but with only the two certain IMI conditions. First, based on the results of Studies 3, 1 (Chapter 2) and 2 (Chapter 3), it was predicted that participants would select larger portion sizes when confronted with the long IMI, compared with the short IMI. Second, the study aimed to explore explanations as to why people are sensitive to the length of an IMI. It was hypothesized that hunger and the subjective reward value of food would increase when participants were confronted with a longer IMI, compared to the short IMI. Third, it was predicted that the certain IMI sensitivity scores from the computerised breakfast IMI task would be highly correlated with the certain IMI sensitivity scores from the real breakfast IMI task. It is important to note that this is an exploratory study which was only powered to address the first hypothesis, but not

necessarily the second or third. In addition, demographic information, as well as liking, familiarity and appetite were assessed.

#### *4.4.1 Methods – Study 4*

##### *4.4.1.1 Participants*

Participants (N = 21; 16 women and 5 men) healthy undergraduate and postgraduate students at the University of Bristol, recruited through the laboratory volunteer database, poster advertisements, and by word of mouth. Participants has a mean BMI of 23.1 kg/m<sup>2</sup> and average age of 20 years. They were asked to contact the research co-ordinator for further details of the study if they were interested in taking part. Exclusion criteria were identical to Study 3. To reduce demand awareness, participants were told that the purpose of the study was to explore ‘the effects of breakfast and lunch on memory’. On completion of the study participants received course credits in remuneration for their assistance. The protocol was approved by the local Faculty of Science Human Research Ethics Committee. One participant dropped out on the second session of the experiment. The final dataset consisted of 20 participants.

##### *4.4.1.2 Sample size determination*

20 healthy participants were recruited for the study. To calculate the required sample size, a power calculation was performed based on the effect size of the difference between food intake at the long and short certain IMI from Study 3, Cohen’s  $d = 0.8$ . On this basis, it was estimated that 20 participants were required to detect differences between real food intake and computerised portion selection with 80% power and  $\alpha = 0.05$ .

##### *4.4.1.3 Foods*

To remove the issues encountered in Study 3 with comparing portion sizes of different cereals types in the computerised and real food IMI tasks, all participants were given a 2L Tupperware of Cheerios (600g) and jug of 500ml milk with a white cereal bowl. The lunch food, 400kcal of cheese and tomato pizza, remained the same as Study 4. The

foods used in the 'desire to eat' reward task were six grapes and one high-protein chocolate breakfast bar. The pizza, grapes and breakfast bar were served on identical white plates (255-mm diameter). The tasters of grapes and breakfast bar were served in small glass dishes.

#### *4.4.1.4 Measures*

All liking, familiarity, appetite and BMI measures were identical to Study 3.

#### *4.4.1.5 Computerised IMI task*

The computerised IMI breakfast task was similar to Study 3, with several changes. First, the photos of the cereal were changed, so that the cereal was presented in a typical white cereal bowl. Second, the conditions were changed to reflect the conditions in the 'real' food intake task – the uncertain IMI condition was removed from the task, so participants had to make portion size selections in response to just a short certain (lunch at 11am) and long certain (lunch at 2pm). The difference in food intake at the long and short IMI was calculated by subtracting the amount of food (kcal) eaten at the short IMI from the amount of food eaten at the long IMI.

#### *4.4.1.6 Food reward tasks*

##### *4.4.1.6.1 Relative reinforcing value of food task*

The RRV of food task was adapted from a questionnaire method that has been validated previously (Goldfield et al., 2005). This measure was shown to correlate ( $r = 0.49$ ) with responses on a concurrent schedule computer task, typically used to assess the RRV of food. For 12 questions, participants were asked to indicate their preference to click the mouse a set number of times to receive either a food reward (100kcal of flapjack) or a non-food reward (50p). The schedule of reinforcement began at an equal fixed ratio of 20 clicker presses to receive either the food or money reinforcer; "Would you prefer to click the mouse 20 times for the flapjack or 20 times for 50p". For each subsequent trial, the number of mouse clicks required for the food increased on a fixed ratio progressive schedule of

reinforcement of 20 presses per question. The 12<sup>th</sup> trial required participants to choose between 20 clicks for the money or 240 clicks for the food. Participants were informed that they would receive the reward after breakfast. To reduce the requirements of the task, and minimize testing time, participants were not required to carry out the mouse clicks for every trial. They were informed, “at the end of the trials, a question number will be selected at random, and you will be required to carry out the number of mouse clicks selected for that question only”. However, because this was a repeated- measures design there were concerns that the number of mouse clicks participants carried out on the first day would influence how much effort they were prepared to exert on the subsequent day. To ensure the task requirements in the first session did not influence performance in the second session, the task was fixed so that the first question, where only 20 mouse clicks were required, was always selected. Participants were under the illusion that this was a random selection. The RRV of food was calculated from the total number of times that food was selected over money.

#### *4.4.1.6.2 Desire to eat and pleasantness*

Following a previously established procedure (Rogers & Hardman, 2015), participants were presented with a peanut and chocolate breakfast bar (198kcal) and grapes (6 × seedless green grapes, 27 kcal). These foods were served one at a time, on a small white 255-mm plate. These foods were specifically chosen to provide one HED and one LED food, both of which are could be typical breakfast foods. For each food, participants were given a bite-sized portion and a full portion on separate plates. They were instructed to eat the bite-sized piece and complete the VAS scales to measure pleasantness and desire to eat. Initially participants were required to rate the pleasantness of the food, with these instructions: “Please rate how pleasant this food tastes in your mouth RIGHT NOW. When making this judgement, IGNORE how much or little of the food you want to eat, and what it would be like to chew and swallow it – JUST FOCUS PURELY ON HOW IT TASTES IN YOUR MOUTH”. Subsequently, they were required to rate their desire to eat the full portion

of each food. For the desire to eat rating the instructions were “Now look at the remaining food on the plate. How strong is your desire to eat, that is, to taste, chew and swallow, the rest of this food RIGHT NOW?” Both the pleasantness and desire to eat scales were anchored with the words ‘NOT AT ALL’ (left hand end) and ‘EXTREMELY’ (right hand end). The order in which each food was eaten and rated was counterbalanced across participants.

#### *4.4.1.7 Procedure*

The procedure was identical to Study 3, with the key difference that participants took part in only two conditions; a short IMI, where participants were told they will receive lunch at 11pm, and a long IMI, where participants were told they will receive lunch at 2pm. Participants completed appetite, fullness, pleasantness measures, as well as the desire to eat and RRV of food task prior to eating breakfast. The breakfast session lasted approximately 30 mins. The lunchtime session was identical to Study 3 and lasted approximately 30 mins. In the second, and final, lunchtime session, participants completed the breakfast IMI computerised task, and had their height and weight measured to calculate BMI. Finally, participants were asked to guess the study aims and hypotheses before being thanked and compensated for their time. The final lunch session was approximately 40 mins long.

#### *4.4.2 Data analysis*

To calculate certain IMI sensitivity, the difference in food intake at the long and short IMI was calculated (kcal). First, to compare food intake at the two certain IMIs, a paired samples t-test was carried out. Second, to test the effects of the length of an IMI on desire to eat, pleasantness and RRV of food, a series of paired-samples t-tests were conducted. Additionally, correlations between hunger at breakfast, pleasantness and desire to eat VAS ratings were assessed to determine whether the reward ratings tapped into significantly different aspects of reward. Third, to assess whether portion selections made in the computerised IMI tasks reflected food intake in response to genuine IMIs, Pearson’s correlations were assessed between real and the computerised certain IMI sensitivity.

### 4.4.3 Results

#### 4.4.3.1 Participant characteristics

One participant dropped out of the second session and was excluded from the analysis. The final dataset consisted of 15 women and 5 men, with a mean BMI of 22.5 kg/m<sup>2</sup> and average age of 20 years. There were 5 participants with missing data on the RRV of food task due to the programme overwriting data. These were included as missing data. All participants were familiar with the test foods. There was little evidence for a correlation between food intake with liking, hunger or fullness at each IMI. Of the 20 participants, only 1 correctly guessed the study aim. See Table 4.2 for participant characteristics and liking ratings.

Table 4.2. Mean  $\pm$  standard deviation and range of participant characteristics and liking ratings (N = 20).

	Mean $\pm$ SD	Range
Age	20.0 $\pm$ 2.4	18.0-34.0
BMI	22.5 $\pm$ 3.3	2.0-11.0
Liking (Pizza)	80.3 $\pm$ 13.9	33.0-100.0
Liking (Cheerios)	68.9 $\pm$ 18.1	29.5-96.0

#### 4.4.3.2 Effect of IMI on food intake, hunger at breakfast, pleasantness, desire to eat and RRV of food

A paired-samples t-test revealed that food intake was higher when the IMI was longer (M = 206.57  $\pm$  94.6 kcal), compared with the short IMI (M = 183.69  $\pm$  94.18 kcal);  $t(19) = 2.05$ ,  $p = 0.04$ . Paired-samples  $t$ -tests revealed that hunger at breakfast, the RRV of food, desire to eat and pleasantness ratings were not significantly different in the long and short

IMI (all  $p > .05$ , see Table 4.3). See Figure 4.2 for visual illustration of the differences between food intake, RRV of food, hunger, desire to eat and pleasantness in the long and short IMI conditions.

Table 4.3. Means  $\pm$  standard deviations (SD) for food reward, hunger at breakfast, fullness, food reward reinforcement, desire to eat and pleasantness of both foods in the long and short IMI conditions (N = 20).

Condition	Mean $\pm$ SD (range)		<i>t</i> - statistic	<i>p</i>
	Short IMI	Long IMI		
Food intake (kcal)	183.7 $\pm$ 94.2	206.6 $\pm$ 94.6	-2.05	0.04*
Computerised breakfast portion size (kcal)	602.0 $\pm$ 319.3	733.0 $\pm$ 319.3	- 4.25	0.00**
Hunger at breakfast (1-100)	58.4 $\pm$ 21.3	54.3 $\pm$ 20.8	0.88	0.39
Desire to eat (breakfast bar: 1-100)	46.5 $\pm$ 26.2	46.0 $\pm$ 26.3	0.08	0.94
Desire to eat (grapes: 1-100)	62.5 $\pm$ 29.9	63.0 $\pm$ 25.2	-0.12	0.90
Pleasantness (breakfast bar: 1-100)	61.6 $\pm$ 24.9	64.3 $\pm$ 22.1	-0.61	0.55
Pleasantness (grapes: 1-100)	73.3 $\pm$ 21.6	72.3 $\pm$ 15.8	0.29	0.78
Food reward reinforcement (point of indifference)	2.3 $\pm$ 3.3	2.1 $\pm$ 3.2	0.17	0.96

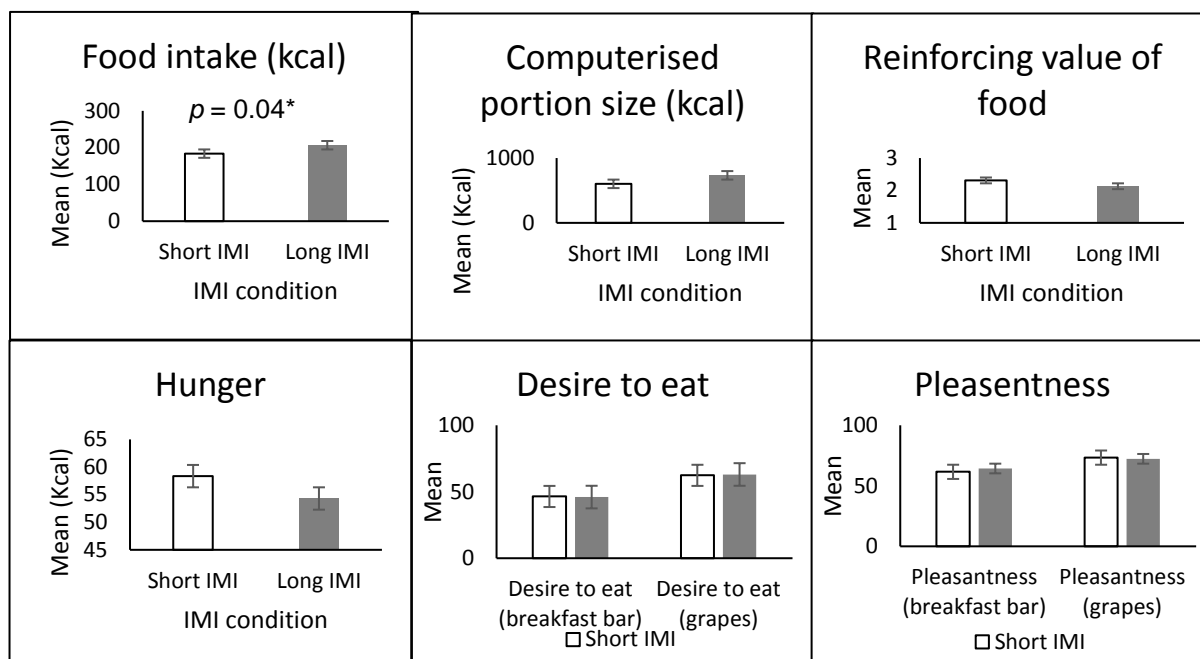


Figure 4.2. Means for food intake, hunger at breakfast, relative reinforcing value of food and desire to eat and pleasantness of grapes and breakfast bar in the long and short IMI conditions ( $N = 20$ ).

#### 4.4.3.3 Comparison between real food intake and computerised IMI tasks

There was little evidence for a correlation between certain IMI sensitivity from the real and computerised breakfast task,  $r = -0.13$ ,  $p = 0.60$ . There difference between the computerised portion sizes at the long and short IMIs was  $131.0 \pm 137.9$  kcal, whereas the difference between food intake at the real long and short IMIs was  $22.9 \pm 50.1$  kcal. See Table 4.3 for mean food intake at the long and short IMIs of the two tasks.

#### 4.4.3.4 Correlations between hunger, pleasantness and desire to eat VAS rating

There was evidence for significantly positive correlations between hunger at breakfast and desire to eat ratings in the short IMI condition, breakfast bar:  $r = 0.46$ ,  $p = 0.04$ ; grapes:  $r = 0.56$ ,  $p = 0.01$ , but not the long IMI, breakfast bar:  $r = 0.11$ ,  $p = 0.66$ ; grapes:  $r = 0.16$ ,  $p = 0.51$ . There was also evidence for significantly high correlations between



pleasantness and desire to eat both foods in the short, breakfast bar:  $r = 0.78$ ,  $p = 0.00$ ; grapes:  $r = 0.69$ ,  $p = 0.001$ , and long IMI conditions, breakfast bar:  $r = 0.41$ ,  $p = 0.07$ ; grapes:  $r = 0.65$ ,  $p = 0.002$ . Similarly, hunger significantly correlated with pleasantness ratings of both foods in the short, breakfast bar:  $r = 0.40$ ,  $p = 0.08$ ; grapes:  $r = 0.49$ ,  $p = 0.03$  and long IMI conditions, breakfast bar:  $r = 0.50$ ,  $p = 0.02$ ; grapes:  $r = 0.71$ ,  $p = 0.00$ .

#### 4.4.4 *Interim Discussion*

In this second study, breakfast intake was measured in response to a long and short certain IMI. In line with the findings from Study 3, Study 1 and 2 (Chapter 2 and 3), results confirmed that participants consume more food when confronted with a longer IMI. Contrary to the secondary hypotheses, there was little change in self-reported hunger at breakfast, desire to eat, or food reward value when the IMI was long, compared to short. As there was little evidence for a significant difference in hunger ratings between the conditions, the effect of state hunger on food intake in response to the length of an IMI could not be assessed. As such, the question as to why people adjust their portion sizes with the length of a future IMI remains unanswered.

The finding that the reward value of food did not change with the length of an IMI is likely to reflect issues with the tasks. The RRV task works on the assumption that all participants will choose the food in the first trial, and therefore will reach an indifference point, where the effort required to obtain the food is greater than outweighs their desire to have it, and they instead choose the money. However, participants in this study did not always choose the food item in the first trial; 6 participants selected the money in the first trial. This could be explained because participants knew they would be receiving breakfast shortly, so did not always value a small bite of food. Alternatively, the sample was made up of students, who may have had a greater tendency to prioritise money over food. Furthermore, 12 of the participants did not reach an indifference point at all because they either selected the money or food for every trial. Therefore, the indifference points from this task cannot be used a valid measure of food reward.

Likewise, methodological limitations may also explain why there was little change in desire to eat across the two IMI conditions. There were high correlations between hunger, pleasantness and desire to eat ratings. This suggests that the desire to eat and pleasantness ratings did not tap into different aspects of food reward. Perhaps a more implicit, empirical measure of food reward that does not rely on subjective self-report is required to test the hypothesis that the length of an IMI influences food reward value. Given these limitations associated with both the RRV and desire to eat task, the hypothesis, that food is perceived to be rewarding when the IMI is longer, merits further testing with an alternative, more reliable measure of reward.

Finally, there was little evidence for a correlation between the computer and real-world certain IMI sensitivity. When correlations have been adjusted for the speculated reliability estimates of the tasks (0.7), the estimated observable correlation between the certain IMI sensitivity scores is 0.19. As the study was only powered to detect an effect size of 0.50 with a sample size of 20, an  $\alpha$  of 0.05 and a  $1-\beta$  of 0.80, this suggests that the study was underpowered to detect a correlation between the real-food and computerised difference in food intake at the long and short IMI. A power analysis revealed that a sample size of 106 would be required to detect this effect with an  $\alpha$  of 0.05 and a  $1-\beta$  of 0.80. Therefore, further testing with a larger sample size is required to explore whether the computerised IMI task is a reliable measure of real-world sensitivity to future meal timings when making portion size decisions. However, given the time constraints and resources required to test 106 participants in this within-subjects study, and the fact that this was not the primary aim of the study, the external validity of the computerised IMI tasks was not tested in Study 5.

Interestingly, the difference in portion size selection in response to the certain IMIs was significantly larger in the computerised, compared to real, breakfast task. This suggests that the people overestimate their portion sizes and IMI sensitivity in the computerised IMI task. Future research is required to assess the extent to which people overestimate their sensitivity to the length of an IMI in the computerised task. Alternatively, the differences in IMI sensitivity scores between the two tasks may be due to demand awareness. The study

aims were not concealed in the computerised task but were in the real task. Therefore, the computerised tasks are more likely to be subject to demand characteristics. Participants may have guessed that they were expected to select a larger portion in response to the longer IMI and adjusted their portion sizes accordingly, thus explaining why a much larger IMI sensitivity scores are observed in the computerised task. This task should be developed to conceal study aims from participants to reduce demand awareness.

#### **4.5 Study 5**

In a third study, breakfast intake was measured in response to a long and short IMI. This was designed as an exploratory study to investigate potential reasons why the length of an IMI influences portion size decisions. This study continued to test the hypothesis that people eat more in response to a longer IMI because they perceive the food to be more rewarding. Given the issues with the food reward tasks used in Study 4, detailed above, the hypothesis was assessed using a different measure of food reward. Implicit reward value can be measured by evaluating a participant's willingness to exert effort to get access to a food (Epstein, Truesdale, Wojcik, Paluch, & Raynor, 2003; Waugh & Gotlib, 2008). When making a decision, one must evaluate the cost of that choice (the effort required to obtain it) against the potential benefits. Handgrip force tasks have been used to gauge the amount of effort that individuals will expend to receive a reward (Ziauddeen et al., 2014; Ziauddeen et al., 2011). High grip force reflects greater subjective reward value; participants have been shown to exert greater force for high value monetary rewards (Pessiglione et al., 2007). In Study 5, the effect of the length of an IMI on reward value of food was measured using a novel handgrip force task. It was predicted that food would be more rewarding, participants will be motivated exert more effort for a food reward, when confronted with a longer IMI, compared to a short IMI. Furthermore, to explore whether the length of an IMI has an influence on food intake because it changes the reward value of food, I planned to establish whether the difference in handgrip force in the long and short IMI predicted the difference in food intake at the long and short IMI.

The results from Study 4 suggest that self-reported hunger did not change with the length of an IMI. An alternative possibility is that individuals choose larger portions when confronted with a longer IMI because they predict that future hunger will be greater. In Chapter 2 and 3, it was speculated that people select larger portions when confronted with a longer IMI because they are planning for expected future hunger and fullness during the IMI. For example, if someone knows there will be a short IMI before dinner, they might refrain from eating too much at lunch to avoid feeling overly full. Conversely, if someone knows they will not have an opportunity to eat during a long IMI, they may consume a larger portion to avoid overly feeling hungry. To test this theory, prospective expectations about lunchtime hunger were assessed in response to the short and long IMI. It was predicted that expected hunger would be higher in the long IMI, and that a greater difference in expected future hunger would predict the difference in food intake at the long and short IMI. Furthermore, with the aim of exploring how explicit concerns about hunger and fullness influence food intake, following previous methods from Chapter 3, participants were asked at the end of the experiment to report whether they were concerned about hunger and fullness in deciding how much food to eat.

An additional explanation for why the length of an IMI influences food intake could be because the IMI changes the expected satiety of food. Expected satiety is considered an essential determinant of meal size and energy intake (Brunstrom, 2014; Brunstrom & Shakeshaft, 2009). In deciding how much to eat, individuals take account of the expected satiety of food. Expected satiety has been shown to be a predictor of self-selected portions (Fay et al., 2011; Wilkinson et al., 2012). Similarly, low expected satiety has been shown to predicts the selection of large portion sizes (Brunstrom & Rogers, 2009). However, it remains unclear how expected satiety is estimated when portion size decisions are complicated by future meal timings. One possibility is that the expected satiety of food is affected by information about future meal timings, which influences portion size decisions. For example, a short IMI could increase the expected satiety of a food, which could drive individuals to eat a smaller portion. To investigate this prospect, the expected satiety of the

test foods was compared at the long and short IMI. To further understand whether certain IMI sensitivity is driven by a change in the expected satiety of food, the relationship between the difference in food intake at the long and short IMI and the difference in expected satiety at the long and short IMI was assessed.

A final possible explanation for why information about the length of an IMI drives food intake was that the length of an IMI alters individuals' perceptions of a 'normal' portion size. It has been shown that hungry participants report their normal everyday portion sizes to be significantly higher (Brunstrom, Rogers, Pothos, Calitri, & Tapper, 2008). The authors speculated that hunger may distort memories of previously consumed portion sizes. In the same way as hunger, the length of an IMI may also distort perceptions of normal portion sizes, which could influence how much food participants choose to eat. This prospect was investigated by assessing whether the anticipated length of an IMI affects participants' perceptions of their normal everyday portion sizes. In line with previous findings that hunger increases normal portion size perceptions (Brunstrom, Rogers, et al., 2008), it was predicted that a longer IMI would lead to larger everyday portion size estimations.

In this study, the effects of the length of an IMI on food intake at breakfast were assessed in a larger sample. First, based on findings from Study 3 and 4, as well as Study 1 and 2 (Chapter 2 and 3), it was predicted that participants would consume more when confronted with a longer IMI. Second, it was predicted that food reward (measured by a novel handgrip force task), expected satiety and expected lunchtime hunger would differ in response to a long and short IMI. Specifically, it was hypothesized that participants would exert more force to receive a food reward when confronted with a longer IMI. In addition, it was hypothesised that in the long IMI condition, expected lunchtime hunger and estimated ideal portion size would be higher, and expected satiety would both be lower. Third, depending on whether there were significant differences in these variables (food reward, expected satiety, expected lunchtime hunger and estimated normal portion size) across

conditions, the factors were intended to be assessed as mediators of the difference in food intake between the long and short IMI.

#### *4.5.1 Methods – Study 5*

##### *4.5.1.1 Participants*

Participants (N = 36) were healthy undergraduate and postgraduate students recruited from the University of Bristol. Exclusion criteria and study aims were identical to Study 3 and 4. On completion of the study participants received course credits or £10 (sterling) in remuneration for their assistance. The protocol was approved by the local Faculty of Science Human Research Ethics Committee. There were 3 participants who dropped out on the second session of the experiment, resulting in 33 participants in the final sample (21 women and 12 men) with an average BMI of 22.5 kg/m<sup>2</sup> and average age of 21 years (See Table 4.4).

##### *4.5.1.2 Tasks*

###### *4.5.1.2.1 Handgrip force task*

A metal frame of a weigh-balance was positioned vertically on a table. The force at which participants squeezed the frame was recorded on a connecting computer. Participants were instructed to 'grip the device for 30 seconds'. Two 150g chocolate bars were positioned next to the device. To ensure all participants liked the food reward, participants were asked to choose which bar they would like to receive. They were informed that the harder they squeeze, the more points they will receive and if they get over a certain threshold of points they will be sent the chocolate bar in the post a week after the experiment. There was a concern that participants would perform differently on the second day depending on whether they had received a reward on the first day. To avoid such order effects, participants were told that they would be given the reward a week after the experiment was over. Participants were informed that they would be sent the chocolate bar in the post and were required to write down their address to validate this. Participants were told that they will not be shown or

told the force they are applying and will have to rely on their instinct. They were then given 30 seconds to squeeze the frame as hard as they wanted. The handgrip force was recorded every second for 30 seconds and an average was calculated across the 30 seconds from the AUC.

#### *4.5.1.2.2 Expected satiety*

Although the ‘method of constant stimuli’ task is considered a robust and reliable measure of expected satiety (Brunstrom, Rogers, et al., 2008), there were issues using this task in the current context. The task required participants to select a portion size of one food that matches the fixed portion size of a different ‘reference’ food. There were concerns that the length of the IMI could affect the expected satiety of both the test food and the reference food. If expected satiety were to change with the IMI, then the expected satiety of the ‘fixed’ reference portion would not be perceived as the same in the two conditions. If the expected satiety of the reference food was not constant across the long and short IMI conditions, changes in the expected satiety of the test food might have been concealed. Therefore, the measure of expected satiation used was based on a previous technique (de Graaf, Stafleu, Staal, & Wijne, 1992) that only requires the expected satiety of one food to be assessed. A randomly selected portion of the food was displayed. The participants were required to change the amount of the food by depressing the arrow keys on a keyboard. The participants were asked to “select how much food you will need to feel FULL.” The expected satiety of the two test foods was measured, Cheerios cereal and cheese and tomato pizza. The order of these comparison foods was randomized across participants.

#### *4.5.1.2.3 Estimated normal portion size*

The task used to measure estimated normal portion size was identical to that used by (cf. Brunstrom, Rogers, et al., 2008). The same 12 commonplace UK foods were used (main meal – chicken tikka masala, ‘eggs, chips, and beans’, lasagne, and ‘pasta and tomato sauce’; side dish – rice, sweet corn, potatoes, and peas; snack food – chocolate, crisps, peanuts, and cake). Participants were presented with a photograph of a portion of food in

each trial/ They were instructed to “Think about whether you would typically eat a larger or smaller portion than that presented. When making your decision you should imagine a typical situation where you are free to select the food and determine the portion size you would like to eat.” Participants were instructed to press the left key when they thought the portion size on the screen was smaller than their normal portion, and the right key when they perceived the portion size to be larger than their normal portion size.

An Adaptive Probit Estimation algorithm was used (c.f. Watt & Andrews, 1981) to improve the efficiency of the psychophysical function by ensuring the participants do not consistently choose either ‘too much’ or ‘too little’. A separate probit analysis was made for each of the 12 foods. Each participant completed 56 trials for each of the 12 food types, resulting in a total of 672 trials. Each set of 56 trials was separated into 7 blocks, with 8 stimuli presentations in each (4 stimulus levels, each presented 2 times). At the end of the second, and every successive block, an approximate probit analysis is made and 4 stimulus levels are chosen based on the analysis, maximising the chance of reaching the point of subjective equality. The re-selecting of stimulus levels provides information that narrows the point of indifference, eventually pinpointing the most accurate estimated normal portion size. This task took approximately 15 minutes to complete, with a self-determined break half-way through the task. The adaptive probit estimation and the code for presenting the stimuli were both written in Matlab (version 6). The graphical interface was implemented using Cogent Graphics software (freeware).

#### *4.5.1.2.4 Expected hunger*

Using a computerised 1-100 VAS scale, participants were asked to report ‘how hungry do you think you will be when you come back in for lunch’.

#### *4.5.1.3 Additional measures*

Measures to assess liking, familiarity, appetite, BMI and the computerised breakfast IMI task were identical to Study 4.



#### *4.5.1.3.1 Post-experiment questions about hunger and fullness concerns*

After completing the experiment, participants were asked about the strategies used to make portion decisions. In two separate questions, participants were asked to report 'to what extent were you concerned about potential future hunger/fullness in deciding how much food to select' on a 100-mm visual-analogue scale. They selected from a range of options (didn't cross my mind, crossed my mind but didn't affect my decision, a little concerned, very concerned). These responses were coded from 1-4, respectively.

#### *4.5.1.4 Procedure*

The procedure was similar to Study 4. However, rather than completing the desire to eat and RRV of food tasks, participants completed the tasks to measure predicted lunchtime hunger, expected satiety, estimated normal portion size and handgrip force prior to eating their breakfast. After the final lunchtime session, participants were asked to answer the post-experiment questions about hunger and fullness concerns. The certain IMI sensitivity (difference in food intake at the long and short IMI) was calculated in the same way as Study 4. Finally, participants were asked to guess the study aims and hypotheses. Participants were debriefed, thanked and compensated for their time.

#### *4.5.2 Data analysis*

Due to a technical issue with saving the data from the estimated normal portion size task, only 10 participants had data from the long and short IMI conditions. Therefore, the results from this task were not analysed. Certain IMI sensitivity was calculated by subtracting food intake (kcal) at the short IMI from food intake (kcal) at the long IMI. Difference scores for predicted hunger, expected satiety, and handgrip force were calculated in the same way - each participant's score recorded at the short IMI condition was subtracted from the score recorded at the long IMI condition.

First, to compare food intake at the two IMIs, a paired samples t-test was carried out. Second, to test the effects of the length of an IMI on hunger, predicted hunger, expected

satiety and food reward (handgrip force), a series of paired-samples t-tests were conducted with hunger, predicted hunger, handgrip strength and expected satiety at the long and short IMIs entered as within-subjects factors. Third, to explore mediators of the difference in food intake at the long and short IMIs, these variables would be included in a mediation analysis depending on whether there was a significant difference in scores (hunger, predicted hunger, handgrip strength and expected satiety) at the long and short IMIs.

### 4.5.3 Results

#### 4.5.3.1 Participant characteristics

The final dataset consisted of 33 participants (21 women and 12 men), with a mean age of 21 years and mean BMI of 22.5 kg/m<sup>2</sup>. There were 3 participants with missing data on the handgrip force task due to technical issues with saving the data. These were entered as missing datum in further analyses. All participants were familiar with both the test foods. Of the 33 participants, none correctly guessed the study aim. See Table 4.4 for demographic information.

Table 4.4. Means  $\pm$  standard deviation (SD) and range of participant characteristics and liking scores (N = 33, 21 women and 12 men).

	Mean $\pm$ SD	Range
Age (yrs)	20.9 $\pm$ 4.6	18.0-44.0
BMI (kg/m <sup>2</sup> )	22.5 $\pm$ 2.6	17.0-28.0
Liking – Pizza (1-100)	80.3 $\pm$ 13.9	33.0-100.0
Liking – Cheerios (1-100)	68.9 $\pm$ 18.1	29.5-96.0

Table 4.5. Means  $\pm$  SD and t-test comparison of food intake, hunger, estimated lunchtime hunger, handgrip force and expected satiety of pizza and Cheerios in the long and short IMI

conditions. Data given as mean  $\pm$  SD (minimum – maximum).  $N = 33$ , 2-way paired t-test long vs short IMI.

Condition	Mean $\pm$ SD (range)		<i>t</i> - statistic (short vs. long IMI)	<i>p</i>
	Short IMI	Long IMI		
Food Intake (kcal)	180.3 $\pm$ (81.8)	205.1 $\pm$ 63.4	-2.96	0.006*
Hunger (1-100)	69.3 $\pm$ 16.89 (1-100)	70.1 $\pm$ 18.6 (1-100)	-0.24	0.81
Predicted Hunger (1-100)	67.9 $\pm$ 21.6 (1-100)	74.9 $\pm$ 17.7 (1-100)	0.01	0.09
Handgrip force (AUC)	261.2 $\pm$ 239.2	227.1 $\pm$ 556.9	0.72	0.48
Expected Satiety – Pizza (kcal)	368.8 $\pm$ 265.7	368.7 $\pm$ 256.1	-0.01	0.99
Expected Satiety - Cheerios (kcal)	370.4 $\pm$ 275.9	369.0 $\pm$ 267.0	0.07	0.99

\* =  $p < 0.05$

\*\* =  $p < 0.001$

#### 4.5.3.2 Effect of IMI length on food intake

A paired samples t-test revealed that food intake was significantly lower when the IMI was shorter ( $M = 180.3 \pm 81.8$  kcal), compared with the long IMI ( $M = 205.1 \pm 63.4$  kcal),  $t(32) = 2.96$ ,  $p = 0.006$  (See Table 4.5). There was a significant correlation between liking of Cheerios and certain IMI sensitivity,  $r = 0.43$ ,  $p = 0.00$ ; participants who reported greater liking of Cheerios tended to be more sensitive to the length of a certain IMI.

#### 4.5.3.3 Effect of IMI length on handgrip force, predicted hunger and expected satiety

There was little evidence that the handgrip force, expected satiety and hunger ratings were significantly different in the long and short IMI conditions (see Table 4.5 and Figure 4.3 for a visual illustration). Given that there was little evidence for significant differences between handgrip force and expected satiety, these factors were not assessed as mediators of the difference in food intake at each IMI.

There was no evidence for a difference between expected lunchtime hunger ratings in response to the long ( $M = 67.9 \pm 21.6$ ) and short IMI ( $M = 74.9, \pm 17.7$ ),  $t(32) = -7.03, p = 0.09$ . However, the small-medium effect size (Cohen's  $d = 0.3$ ) suggests that the study was underpowered to detect a difference in expected hunger between the long and short IMIs. A post-hoc power calculation states that a sample of 121 participants would be required to detect an effect with an  $\alpha$  of 0.05 and a  $1-\beta$  of 0.80.

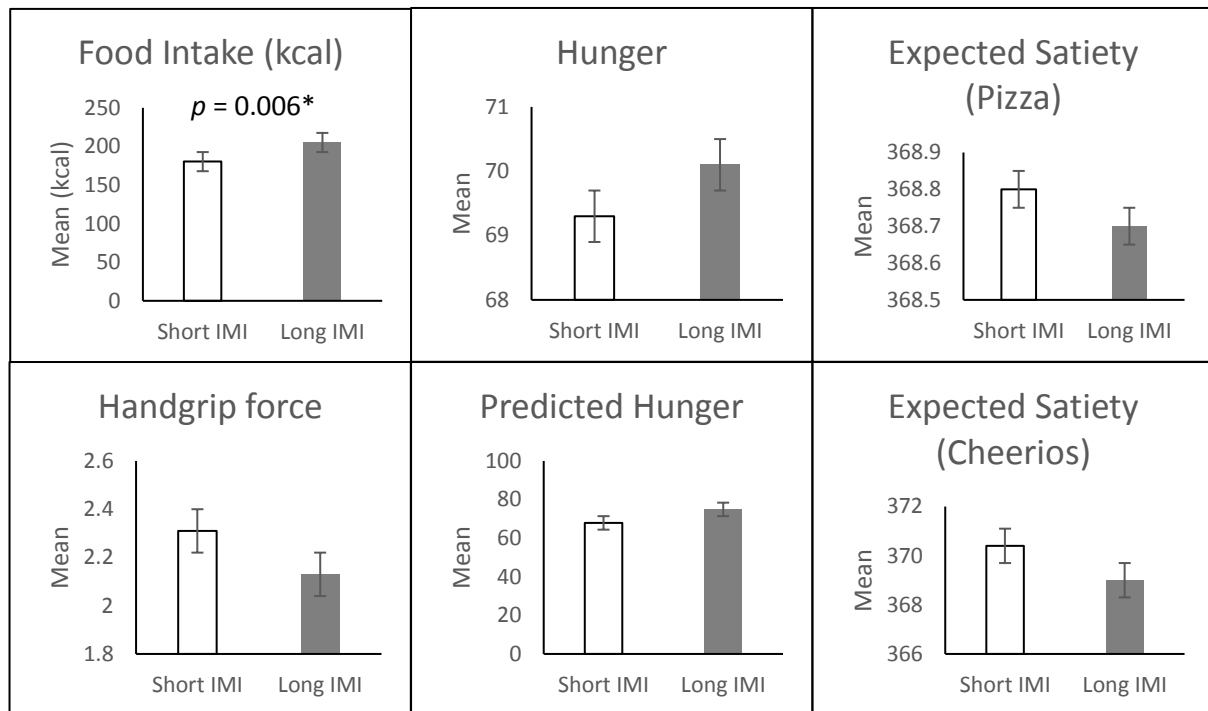


Figure 4.3. Means for food intake (Kcal), hunger, predicted lunchtime hunger, and expected satiety of pizza and Cheerios in the long and short IMI conditions ( $N = 33$ ).  $P$ -values reflect significant pairwise comparisons between the long and short IMI conditions.

#### 4.5.3.4 Post-hoc analysis combining data sets from Study 3, 4 and 5

The data from all 3 studies was combined to assess the relationship between consistent variables with greater power ( $N = 79$ ). To explore the unexpected relationship between IMI sensitivity and liking found in Study 5, correlation between liking of Cheerios and certain IMI sensitivity was measured. There was no evidence for a significant correlation between liking and certain IMI sensitivity ( $r = -0.15, p = 0.10$ ). Given the power provided by combining the data across studies, the relationship between IMI sensitivity and relevant

individual differences, namely BMI, was measured. There was no evidence for a correlation between certain IMI sensitivity and high BMI ( $r = 0.08$ ,  $p = 0.50$ ).

#### 4.6 Overall discussion

In all three experiments, participants tended to eat larger portions of food in response to a longer IMI. This supports the findings from Studies 1 and 2 (Chapter 2 and 3), that individuals adjust their portions sizes according to the timing of their next meal. Interestingly, liking of Cheerios was associated with the difference in breakfast intake between the long and short IMI, however this relationship did not withstand when assessed in the data combined across all three studies. By replicating the results from Chapter 2 and 3 with real food intake and genuine IMIs, the conclusion that the influence of meal timings on portion selection can be generalised to more real-world food intake. This finding has possible implications for future empirical studies assessing portion size. There is likely to be great variability in participants' future meal timings when taking part in experiments, which would differentially affect portion size decisions. As these results suggest that the length of an IMI influences portion size selection, it is advised that future meal times should be controlled for or included as a covariate in studies measuring portion size selection and food intake.

Data across the studies did not show a relationship between BMI and certain IMI sensitivity, thus failing to replicate findings from Chapter 3 (Study 2). However, this can be attributed to the limited BMI range. A similar null relationship between certain IMI sensitivity and BMI was observed in Study 1 (Chapter 2), suggesting that the association between BMI and IMI sensitivity only emerges when with a high BMI are included in the sample. Subsequent analysis is required to replicate the association between IMI sensitivity and BMI in a real food intake study with genuine IMIs.

A key aim of Study 4 and 5 was to further understand underlying reasons why the length of an IMI influence food intake. In Chapter 2 and 3, it was speculated that people might be concerned about possible future hunger or fullness during the IMI, and so select larger portions to starve of hunger during the long IMI. There was weak evidence that people

expected to be hungrier at lunchtime when the IMI was longer, compared to short, however the medium effect size suggests that the study was underpowered to show an effect. The effect would be congruous with the change in food intake, suggesting that participants ate larger portions more when confronted with a longer IMI, because they expected to be hungrier at lunchtime. Nevertheless, due to the lack of power to show a difference in expected hunger in response to the long vs. short IMI, it is unclear as to whether the change in expected hunger was a driver of portion size selection. While many studies have focused on the role of the expected satiating properties of food as a driver of portion selection (Brunstrom & Rogers, 2009), predictions about future hunger have received little attention. Future studies should seek to establish whether expectations about hunger drives food intake in response to the length of an IMI. Furthermore, expected fullness (aka, how full do you think you will feel before your next meal), which was not measured in this study, could also lead individuals to eat less food when the IMI is shorter in order to protect against future over-fullness. Subsequent research is required to investigate how predictions about future fullness relate to portion size selection in response to different length of an IMI.

It is also important to highlight that in post-experiment questionnaires, 87% of participants reported feeling unconcerned about future hunger when deciding how much cereal to eat at breakfast. A similar trend was observed in Chapter 3; little evidence suggested that portion size selection was influenced by participants' overt concerns about hunger and fullness during the IMI. This suggests that if expectations about future hunger do influence portion selection in response to the length of an IMI, this is likely to be an implicit process. Subsequent studies are required to assess whether expected hunger or fullness drives sensitivity to the length of an IMI covertly or overtly.

There was little evidence to support the hypothesis that expected satiety of a food changes with the length of an IMI. This finding suggests that the expected satiety of a food is not influenced by anticipated meal timings. One possibility is that the task was not a reliable measure of expected satiety. The task has been criticised because it has not been shown

that can reliably predict how long foods will stave off hunger for (Brunstrom, Shakeshaft, et al., 2008), and these types of ratings are often subject to bias (Poulton, 1979). The 'method of constant stimuli', where participants select a portion of a test food expected to provide the same satiety as a fixed portion of a different reference food, is considered to be robust and reliable because it can sensitively measure differences in expectations across foods (Brunstrom, Shakeshaft, et al., 2008). This version of the task was not included due to concerns that the length of an IMI would influence the expected satiety of both the test food and the reference food, which should be fixed across trials. In the future, a task should be designed in which the expected satiety of the reference food is held constant, and not potentially affected by the IMI, to magnify the effects of the length of an IMI on the expected satiety of a test food.

Similarly, in both Study 4 and 5, there was little evidence to suggest that the length of an IMI changes the reward value of food. No differences between the long and short IMIs were observed in handgrip force, RRV of food or desire to eat, suggesting that the length of an IMI does not have an influence on the subjective reward value of food. However, both the RRV of food and handgrip force tasks were novel and piloted for the first time in these experiments. Limitations of the reinforcing value of food task were outlined in the discussion of Study 4. Now, methodological issues with the handgrip force tasks will be discussed.

One explanation as to why meal timing did not influence motivation to exert effort on the handgrip force task is because participants were informed that they would receive the reward based on their average handgrip force from both sessions. Thus, the two separate measures of handgrip force (long and short IMI) were not independent; performance on the first session may have influenced performance on the second. For example, participants may have been trying to match the effort exerted in the first session with the effort exerted on the second session or may have tried to exert more or less force than they did on the second session. Although the condition order was counter-balanced across participants to reduce such order effects, the performance on the first session could have influenced

performance on the second session. In the future, this could be resolved by instructing participants that they will receive two separate food rewards, one based on their handgrip force on the first day and one based on their handgrip force on the second day. An additional issue with the handgrip force task is that participants might have interpreted the task as a challenge to exert as much force as possible. For example, participants may have squeezed as hard as they could in both the long and short IMI conditions, thus concealing more subtle differences in the subjective reward value of food. Alternatively, participants may not have believed that they were going to receive the food, and so their handgrip force did not reflect their motivation to exert effort to receive the reward. Given the methodological issues associated with the reward value tasks implemented in Study 4 and 5, subsequent testing with a more robust and reliable measure of food reward is required to test the hypothesis that the length of an IMI drives portion size selection by changing the reward value of food.

Additionally, the sample sizes in the three studies were small, so were not powered to look at individual differences. Given the limited power to test individual differences, the decision was made to exclude monetary delay discounting from the study. This is a significant limitation, as the relationship between monetary delay discounting and sensitivity to the length of the certain IMIs was not assessed. Exploring differences in delay discounting may have helped to tease apart differences in future orientation that underpinned IMI sensitivity, as in Study 1 (Chapter 2). Subsequent experiments should be conducted with a larger sample size, to investigate whether steeper delay discounters are less sensitive to genuine IMIs when making real portion size decisions. A further limitation is that we did not check whether participants had abstained from eating between breakfast and lunch as instructed. It is possible that participants could have planned to ignore the instruction and eat during the IMI, which may have influenced their portion sizes decisions. Future replications should include manipulation check to ensure participants adhere to the instructions, so we



can insure that information presented about the IMI is driving portion size, rather than participants' own IMI plans.

Finally, due to technical issues with the estimated normal portion task, the hypothesis that the length of an IMI changed perceptions of a 'normal' portion size could not be assessed. This should be investigated in future studies to establish whether perceptions of a normal portion contribute to differences portion selection in response to a long vs. short IMI.

#### *4.7 Chapter conclusion*

In all three studies, results supported the findings from Chapter 2 and 3, confirming that individuals consume more food when confronted with a longer IMI. However, there was little evidence that being uncertain about length of an IMI influences food intake. Study 4 and 5 aimed to investigate *why* people select larger portions in response to a longer IMI. The findings suggest that participants expected lunchtime hunger to be greater at the long, compared to the short, IMI. These findings were discussed in the context of beliefs about hunger, and techniques to alleviate concerns about hunger were proposed as a potential portion size reduction strategy. However, further research is required to understand whether differences in expected hunger drives portion selection in response to future meal timings. There was little evidence to suggest that information about the length of an IMI influenced expected satiety or food reward. Nevertheless, it is argued that these null findings may reflect issues with the novel tasks, or that the studies were underpowered to show an effect.

#### *4.8 Acknowledgments*

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## 5 Chapter 5. Studies 6, 7 and 8.

### Assessing 'chaotic eating' using self-report and the UK Adult National Diet and Nutrition Survey

This chapter (Studies 6 and 7) is adapted from a paper published in *Physiology and Behaviour* with Zimmerman as first author (Zimmerman, Johnson, & Brunstrom, 2018). The author was responsible for the design, implementation, participant recruitment, data collection, analysis and interpretation of the data reported in Study 6 and 7. The author was responsible for the analysis and interpretation of the data reported in Study 8. Laura Johnson was responsible for collating the data from the UK Adult National Diet and Nutrition Survey. The data from Study 7 was from the same experiment as Study 2 (Chapter 3). The sample sizes differ as in Study 2 the analysis was restricted to participants who came in during lunch hours (11am-2pm), whereas this constraint was not necessary in Study 7, hence the full sample were used.

#### 5.1 Chapter Outline

Studies 3, 4 and 5 (Chapter 4) explored the influence of planned meal timings on real food intake, as well as individual differences and mechanisms that underpin IMI sensitivity. There was little evidence from Studies 1 (Chapter 2), 2 (Chapter 3), 3, 4 and 5 (Chapter 4) to suggest that uncertainty about the timing of future meals leads to larger greater food intake. Nevertheless, reduced sensitivity to uncertain IMIs was linked to high BMI in Study 1 and 2 (Chapter 2 and 3). It remains unclear how uncertainty about future meal timings influences portion size decisions or weight gain. The focus of this chapter was to explore implications of eating patterns that involve irregular, and often uncertain, meal timings. Despite recommendations that people eat at regular meal timings as a weight loss strategy, there is limited evidence to support these guidelines. The aim of this chapter was to test the claim

that 'chaotic eating', eating at irregular or variable meal timings, is linked to high BMI. In Study 6 an initial measure of variability in meal timings is presented. This measure is refined in Chapter 7, to create an index of chaotic eating. The aim of Study 7 was to test the measure and assess the relationship between chaotic eating with BMI and eating behaviour. The hypotheses were tested again in Study 8 using a larger sample with a more robust measure of meal timings from weighed diet diaries obtained from the National Diet Survey Data. Associations between chaotic eating of snacks and meals with BMI, food intake and eating behaviour were explored.

The aims of this chapter are:

1. To develop a measure that assesses individual differences in chaotic eating (day-to-day variability in the timing of meals and snacks).
2. To investigate the association between chaotic eating and BMI.
3. To understand how chaotic eating relates to eating behaviours that might promote or modify weight gain, such as dietary restraint, hunger, disinhibition, emotional, external and restrained eating.

## 5.2 *Introduction*

Day-to-day patterns of food intake are thought to play an important role in determining chronic energy balance, and researchers have taken an interest in specific eating patterns that might promote obesity (Ma et al., 2003). Specifically, eating irregularly or at unstructured times is increasingly recognised as an eating pattern related to, and potentially contributing to, the aetiology and development of obesity (Karkkainen, Mustelin, Raevuori, Kaprio, & Keski-Rahkonen, 2018; Lane & Szabo, 2013; Westenhoefer, von Falck, Stellfeldt, & Fintelmann, 2004). Irregular eating is also considered a risk factor for junk food consumption (Zahra, Ford, & Jodrell, 2014), weight gain (de Vos et al., 2015) and obesity (Ekmeckioglu & Touitou, 2010). However, researchers use different definitions and measures of irregularity. Some have assessed irregularity or variability in the size of specific meals and snacks, while others have assessed total energy intake from one day to the next.

The latter is found to be positively associated with BMI and this has been attributed to variability in the size of evening meals (Pot et al., 2014; Pot, Hardy, & Stephen, 2016). Alternatively, irregularity has been described as variability in the day-to-day frequency of eating occasions. These studies indicate that the effect of irregular eating frequency may be meal specific. For example, a positive association has been observed between BMI and irregular breakfast consumption (Berkey et al., 2003; Rodrigues et al., 2016; Yang et al., 2006), but not with an irregular frequency of other meals (Lehto et al., 2011). In controlled studies, irregular eating frequency is found to increase energy intake, decrease the thermic effect of food (Alhussain et al., 2016; Farshchi, Taylor, & Macdonald, 2004a; Farshchi et al., 2005a), and reduce insulin sensitivity (Farshchi, Taylor, & Macdonald, 2004b; Farshchi et al., 2005a). Other studies show that those who self-classify themselves as having an irregular eating frequency tend to have a higher BMI (Kagamimori et al., 1999; Takahashi et al., 1999), a higher prevalence of metabolic syndrome, and increased insulin resistance (Sierra-Johnson et al., 2008). Clearly, several aspects of irregularity in eating patterns have been assessed, with various definitions of irregularity.

Given that 'irregular eating' could reflect irregular day-to-day energy intake, day-to-day eating frequency, inconsistent consumption of specific meals or variability in meal timings, the effects of irregularity on eating behaviour and BMI can be misrepresented. For instance, in several countries, including the UK, Australia, and Canada, regular meal timings are recommended for weight loss (Canada, 2017; Gov.au, 2012; NHS, 2017). Similarly, cognitive behavioural therapies for binge eating and obesity prescribe a regular, structured, meal pattern (Graham & Reynolds, 2013; Palavras et al., 2015). Despite these guidelines, studies have neglected to research irregularity in the *timing* of eating occasions. A systematic review of eating patterns and obesity found no evidence to support the hypothesis that irregular eating timings promote weight gain (Mesas et al., 2012). Furthermore, findings presented in Studies 1 (Chapter 2), 2 (Chapter 3), 3, 4 and 5 (Chapter 4) failed to show that uncertainty about the timing of future meals significantly effects food

intake. Nevertheless, findings from Study 1 (Chapter 2) did suggest that delay discounting is more likely to be expressed when meal timings are uncertain, and this may promote eating behaviours that lead to a high BMI. Given these contradictory findings, it remains unclear as to whether uncertain meal timings affect portion size decisions or BMI. It is important to resolve these mixed findings by establishing whether individuals with a high BMI are more likely to engage in eating patterns where meal timings are uncertain. It is important to note that irregular day-to-day meal timings are not necessarily uncertain, but it is presumed that uncertainty about the length of an IMI is probably greater than when meal timings are regular.

For the first time, two studies are reported that explored the relationship between BMI and irregularity in the timing of eating occasions. The expression ‘irregular eating’ has multiple, distinct definitions; hence, the novel term ‘chaotic eating’, reflecting variation in the *timing* of eating occasions, is introduced. See Figure 5.1 for a visual depiction of the difference between high and low chaotic eating (variability in timings), and how this differs from irregular day-to-day eating frequency.

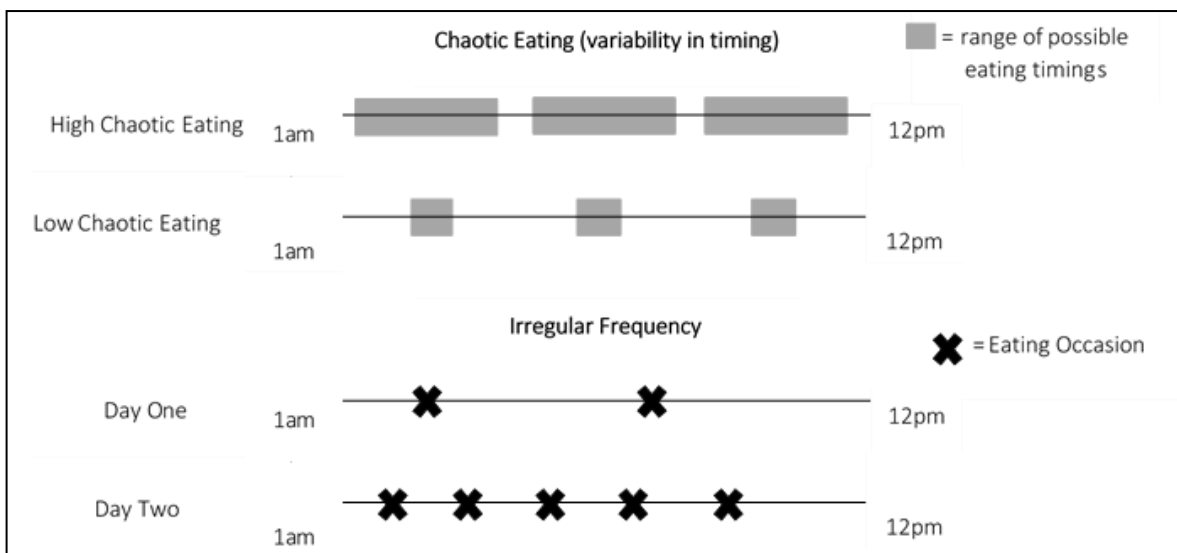


Figure 5.1. Visualisation of the concept of chaotic eating (variability in the timing of eating occasions) compared to irregular eating frequency. Differences in the range of possible meal-timings of a high and low chaotic eater are depicted, whilst eating frequency is

constant at 3 times a day. In addition, the figure shows irregular day-to-day eating frequency to illustrate how this differs from chaotic eating.

It was hypothesised that chaotic eating would be associated with BMI. There is speculation that high variability in the timing of eating occasions allows individuals to obtain food at any time, which encourages overeating (Bellisle, 2014; Berteus Forslund et al., 2002). A chaotic lifestyle, in which eating timings are more variable, might impair an individual's ability to plan the timing of future meals. Eating at unplanned times of day might create uncertainty about when food will next be available. In Studies 1 (Chapter 2) and 2 (Chapter 3), a negative association was observed between BMI and sensitivity to uncertain and certain IMIs, suggesting that individuals with a high BMI are less likely to plan for future meals. If individuals with a high BMI do not engage readily in meal planning behaviours, they are more likely to eat chaotically.

Chaotic eating, and failure to plan, might also increase the likelihood that individuals will succumb to emotional or external food cues and triggers. Some evidence suggests that weight gain is evident in people who are especially cue reactive or who tend to engage in 'emotional eating' (Boswell & Kober, 2016; Singh, 2014). To explore how chaotic eating relates to these traits, relationships between chaotic eating and established measures of external and emotional eating were assessed. In addition, the association between restrained eating and chaotic eating was explored. It was predicted that restrained eaters might plan for future energy intake and eat less spontaneously.

Circadian timing of food intake could also be a pathway whereby chaotic eating could influence BMI. Studies have linked the timing of meals to weight regulation (Jakubowicz et al., 2013), as well as glucose control and insulin secretion (Morgan et al., 2012). Studies report more successful weight loss outcomes among obese women with a flatter, less fragmented circadian rhythm pattern (Bandin et al., 2014). Research on temporal eating patterns demonstrates that evenly spaced meals of the same size are associated with better diet quality (Eicher-Miller et al., 2016), and a 'grazing' temporal eating pattern is associated

with poorer diet quality and adiposity among women (Leech et al., 2017). Similarly shift workers, who eat at unusual, possibly irregular hours, tend to have a higher risk of cardiovascular disease (Esquirol et al., 2011) and obesity. These studies suggest energy intake regulation is linked to the circadian clock. Furthermore, evidence suggests that meal timing also regulates circadian rhythms (Wehrens et al., 2017). One possibility is that variable meal timings could lead to more fragmented circadian rhythms, which could promote weight gain.

An additional possibility is that chaotic eating might lead to weight gain by reducing the efficiency of the cephalic-phase response, the physiological response that prepares the digestive system for eating (Mattes, 1997). There is evidence to suggest that an irregular meal pattern can impair digestive functioning; irregular meal frequency has been shown to decrease the thermic effect of food, lower postprandial glucose-response (Alhussain et al., 2016; Farshchi et al., 2004a, 2005a), reduce insulin sensitivity and increase the insulin response to a test meal (Farshchi et al., 2004b). Similarly, studies have found that self-reported irregular eaters have greater insulin resistance (Farshchi et al., 2005a; Sierra-Johnson et al., 2008). Hence, chaotic eating could influence digestion and, consequentially, promote weight gain.

Alternatively, chaotic eating could reflect a predisposition to respond to internal signals of an energy deficit or surplus. Given that the caloric value of a meal can vary greatly, for example from 100 kcal snack to 1000 kcal meal, chaotic eaters might respond to variability in energy intake by eating in response to their hunger and satiety signals, rather than at set meal timings. For instance, chaotic eaters could show better compensation for a high calorie, and more filling meal, by choosing a longer IMI. This would mean energy was being supplied when it was needed on an acute basis, rather than at regular times. Conversely, if someone eats habitually at the same time each day, they may consume a set amount of energy regularly that may be surplus or deficient to requirements. Hence, regular eating could reduce an individual's capacity to correct an energy deficit or surplus. As

individuals with a lower BMI are shown to have a greater tendency to eat in response to hunger and satiety signals (Camilleri et al., 2016; Madden, Leong, Gray, & Horwath, 2012), one possibility is that chaotic eating could prevent weight gain.

In this chapter, results are reported from three experiments that investigated variability in meal timings and chaotic eating. In these studies, a novel measure of chaotic eating is presented, reflecting variability in the timings of eating occasions. Chaotic eating can be assessed by establishing the number of different times during which an individual eats over the course of a week. In Study 6, self-reported variability in timings of both meals and snacks was measured. In Study 7, an additional measure of frequency of meals and snacks was included to calculate chaotic eating scores. In addition, the sample was expanded to include obese, overweight and lean participants. In Study 8, the same chaotic eating index was measured using data from weighed diet diaries from the UK National Diet and Nutrition Survey (NDNS) of adults 2000-2001. In all three studies, it was predicted that chaotic eating would be associated with BMI. To understand how chaotic eating relates to eating behaviours that might promote or modify weight gain, measures of restrained eating, hunger, and disinhibition were included in Study 6 and 7. In Study 8, the Dutch Eating Behaviour Questionnaire (DEBQ; Strien, Frijters, Bergers, & Defares, 1986) was used to measure subscales of emotional, external and restrained eating.

### **5.3 Study 6**

#### *5.3.1 Methods – Study 6*

##### *5.3.1.1 Participants*

Participants ( $N = 62$ ; 41 females, 21 males) were members of the public, recruited through our laboratory volunteer database. Participants were excluded if they were 1) vegetarian or vegan, 2) not fluent in English, 3) taking any medication that might influence appetite or metabolism (except for oral contraceptive pills), or 4) allergic or intolerant to any foods. They received £5 (sterling) for participating in the study. See Table 5.1 for participant



characteristics. The protocol was approved by the local Faculty of Science Human Research Ethics Committee.

#### *5.3.1.2 Snack time variability*

Using a computerised task, participants were asked to select all possible times at which they might eat a snack. Participants were shown a range of tick boxes labelled with half hour intervals on a 24 hour clock. In turn, they responded to the question 'For a typical week, when is it conceivable you might eat a snack? If the timing of your snacks varies considerably, just select more times where it is conceivable you might eat. For example, if you might eat a snack between 12pm and 2pm, select all times from 12-2pm, i.e. 12:00, 12:30, 13:00, and 13:30.' Responses were summed to give each participant a score of total number of possible snack times.

#### *5.3.1.3 Procedure*

Participants completed one 15-minute session. Participants completed the questionnaires to assess chaotic eating patterns. This was part of a larger study investigating food choice, hence additional measures were included. Finally, their height and weight were measured. Participants were debriefed, compensated, and thanked for their time.

#### *5.3.2 Data analysis*

Snack time variability scores were calculated by summing the number of time points selected by each participant. A linear regression analysis was run to assess associations between snack variability with BMI. Snack variability was included as the independent variable and BMI as the outcome variable. Age and gender were also included as predictors. Unstandardized betas ( $\beta$ ) from this model are presented. Analyses were completed in SPSS version 23 (SPSS, Inc., Chicago, IL, USA).

### 5.3.3 Results

#### 5.3.3.1 Participant characteristics

Snack variability times were normally distributed, as assessed by Shapiro-Wilk's test ( $p = 0.02$ ) and there were no outliers in the data, as assessed by inspection of boxplots and standard deviations. The final dataset comprised 62 participants (41 females, 21 males) had a mean age of  $23.6 \pm 7.2$  years and a mean BMI of  $22.2 \pm 3.3$  kg/m<sup>2</sup>. See Table 5.1 for Pearson's correlations between variables.

Table 5.1. Pearson correlations between BMI, snack time variability, age and gender from Study 6 ( $N = 62$ ).

	BMI	Snack Time Variability	Age	Gender
BMI		-0.12	0.49**	-0.25*
Snack Time Variability			-0.12	-0.22
Age				-0.13
Gender				

\* =  $p < 0.05$

\*\* =  $p < 0.001$

#### 5.3.3.2 Relationship between BMI and snack time variability

Snack time variability did not significantly predict BMI,  $\beta = -.01$ ,  $p = 0.75$ . Age significantly predicted BMI,  $\beta = 0.21$ ,  $p = 0.001$ , but gender did not,  $\beta = -1.29$ ,  $p = 0.12$ . See

Figure 5.2 for a visual illustration of this relationship.

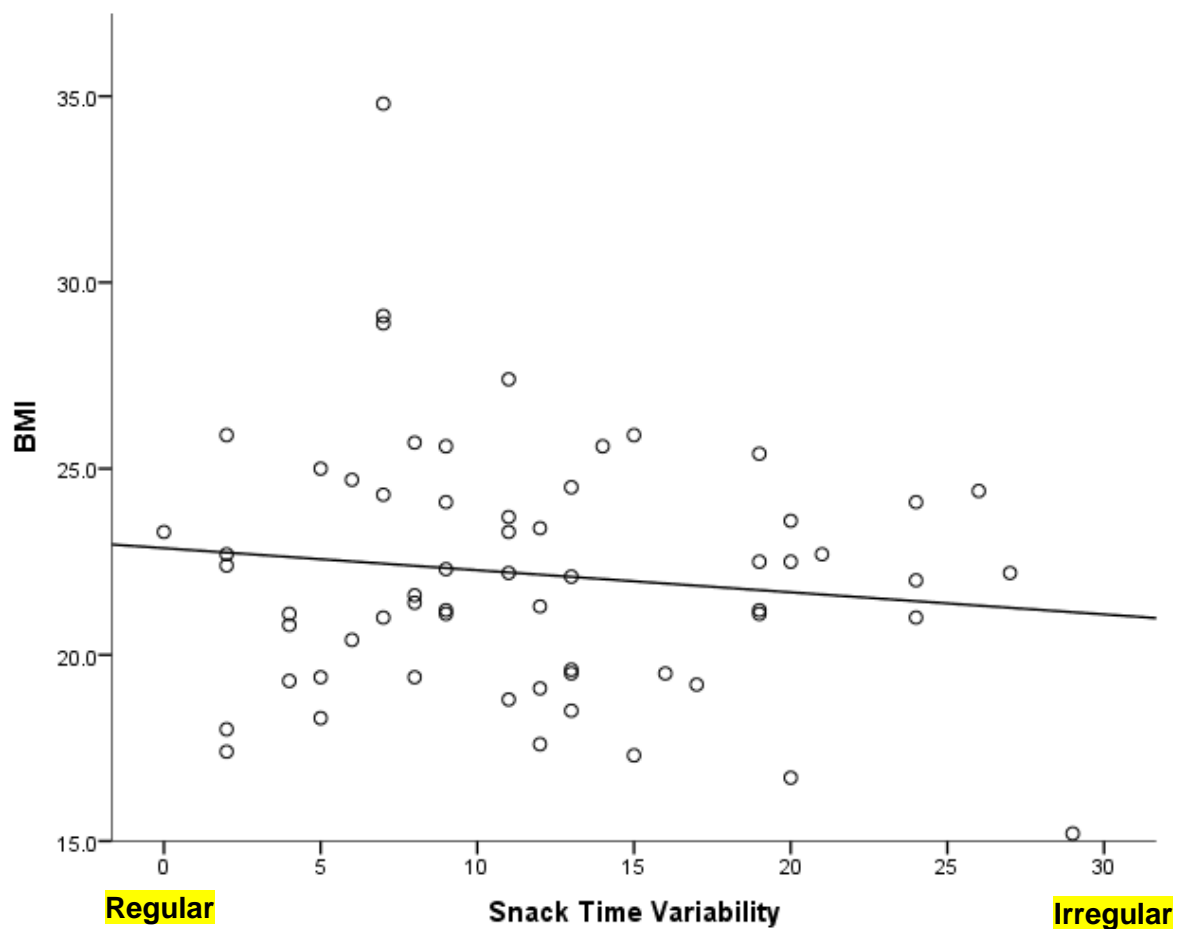


Figure 5.2. Relationship between BMI and self-reported snack time variability for Study 6.

#### 5.3.4 Interim discussion

Using a novel measure of chaotic eating, no significant association between BMI with snack time variability was established. In fact, the (non-significant) relationship was in the opposite direction to the predictions; those with a high BMI had less variability in snack timings. The potential methodological limitations of the chaotic eating measure that could explain this null finding are discussed below.

##### 5.3.4.1 Methodological Issues

In Study 6, chaotic eating was defined as variability in the timings of eating occasions. However, it transpired that measuring frequency of snacks is also critical for

accurately assessing variability in eating times. Initially, it was thought that chaotic eating could be measured by simply summing the number of different timings at which an individual eats over the course of a week. However, the number of unique times will increase with a higher frequency of eating occasions. Eating frequency, defined by the number of occasions an individual eats (Saunders, 1999), is conceptually different from chaotic eating. For example, a person may report 6 unique time points when a meal is consumed over a week. However, if that person eats 6 meals a day, then there is no variation in the timing of these meals, hence they would be considered frequent, but not chaotic. Conversely, if they report eating a meal at 6 different time points over a week, but only eat one meal a day, they would be regarded as infrequent and chaotic. Therefore, to establish a measure of chaotic eating that captures variability in the timing of individual eating occasions, it is necessary to divide the number of possible meal timings over a week by the frequency of meals. Therefore, the methods of Study 6 were repeated in a second experiment, but a measure of eating frequency was also included to allow a more valid assessment of chaotic eating.

An additional weakness of Study 6 is that variability in snack but not meal, time was assessed. To gauge a true measure of chaotic eating, it is important to assess variability of meal timings. Given that meals are typically more structured than snacks, meal time variability may be a more sensitive measure of eating irregularity. In the subsequent study chaotic eating of both meals and snacks was measured. Furthermore, participants might have been misled by the instructions to reflect on a typical week of eating, as timings may differ on weekends compared to week days. Confusion surrounding these instructions might have contributed to the null findings; for example, some participant might have reported a typical weekday, some a typical weekend and some both weekdays and weekends.

A final limitation is that the sample in Study 6 recruited participants who were normal rather than overweight. The range of BMI was very narrow; 80% of participants had a BMI under 25kg/m<sup>2</sup>, thus falling into the healthy or underweight categories. This group did not show as much BMI variability as might be found in the general population; where 67% of

men and 57% of women in the UK have BMIs over 25 (Ng et al., 2014). To assess the relationship between overweight and chaotic eating, it is important to compare chaotic eating behaviours in normal weight with overweight individuals. Thus, a sample with a wider BMI range was used to test the same hypothesis in the subsequent study.

#### **5.4 Study 7**

To address the concerns detailed above, the methods of Study 6 were repeated with methodological corrections. A similar questionnaire was used to quantify snack and meal variability. However, a measure of both *variability and frequency* of snacks and meals was included. Quantifying the frequency of snacks and meals would allow for a more sophisticated measure of variability. It was expected that a measure designed to incorporate both frequency of eating occasions and variability of timings would tap into a chaotic eating style. The primary hypothesis was that the novel measure of snacks and meals would correlate with BMI.

In addition to adapting the measure of chaotic eating, the BMI range was extended by repeating the study in a sample of participants who fell into each weight category, 'normal', overweight and obese. In so doing, the objective was to determine whether a relationship between meal/snack variability and BMI can be observed when participants with a broader range of BMIs are included. Finally, to understand how chaotic eating relates to eating behaviours that might promote or modify weight gain, measures of restraint, hunger and disinhibition were assessed using the TFEQ.

##### **5.4.1 Methods – Study 7**

###### **5.4.1.1 Participants**

Participants ( $N = 115$ ; 63 females, 51 males, 1 transgender) had a mean age of 32.9 years  $\pm 10.9$  and a mean BMI of  $28.4 \pm 6.9$  kg/m<sup>2</sup>. All participants were members of the public and not students and were recruited through our laboratory volunteer database. To reduce demand awareness, participants were told that the purpose of the study was to explore “the relationship between food choice and mood.” Participants were excluded if they

were 1) not fluent in English, 2) taking any medication that might influence appetite or metabolism (with the exception of oral contraceptive pills), 3) vegan or vegetarian (This data was collected as part of a larger study which involved non-vegetarian/vegan foods), or 4) allergic or intolerant to any food. Participants completed an initial pre-screening questionnaire, which included an assessment of their height, weight, age, and gender. Based on the self-reported data, participants were classified as in the “normal” range ( $\text{BMI} < 25\text{kg/m}^2$ ), overweight ( $25\text{ kg/m}^2 < \text{BMI} < 30\text{ kg/m}^2$ ), and obese ( $\text{BMI} > 30\text{kg/m}^2$ ). From these responses, a sample with a wide BMI range was selected. The final sample comprised 47 in the “normal” range, 33 overweight, and 35 participants with obesity. Informed consent was received from all participants and they received £30 (sterling) for participating in the study. This study was part of the same experiment reported in Study 2 (Chapter 3). The protocol was approved by the University of Bristol Faculty of Science Human Research Ethics Committee.

#### 5.4.1.2 *Chaotic eating*

Participants were asked to select all possible times at which they might eat a meal. Participants were shown a range of tick boxes labelled with half-hour intervals on a 24-hour clock. In turn, they responded to the question “For a typical week, when is it conceivable you might eat a meal? If the timing of your meals varies considerably, just select more times where it is conceivable you might eat. For example, if you might eat a meal between 12pm and 2pm, select all times from 12-2pm, i.e. 12:00, 12:30, 13:00, and 13:30.” Participants were then asked to report their meal frequency, “On a typical day, how many times would you eat a meal?” These measures were then repeated with otherwise identical questions related to snack consumption. For each participant, the number of 30 minute time slots reported by each participant was summed. To calculate a meal chaotic eating index, the number of 30-minute time slots was divided by the frequency of meals. A snack chaotic eating index was derived in the same way. A high chaotic eating index indicates that the timing of an individual eating occasion is highly variable.

#### 5.4.1.3 TFEQ

The TFEQ was identical to Study 1 (Chapter 2) and Study 2 (Chapter 3).

#### 5.4.1.4 Procedure

Participants completed a computerised version of the chaotic eating questions, followed by the TFEQ and then provided a measure of their height and weight. BMI was calculated from measured weight/height<sup>2</sup>. As this experiment was part of the same experiment as Study 2 (Chapter 3), additionally tasks were included, so participants were tested for approximately two hours. Measures included an IMI sensitivity task, delay discounting, food choice and interoceptive awareness tasks. These measures were used to test unrelated hypotheses. At the end of the study the participants were debriefed, compensated and thanked for their assistance.

#### 5.4.2 Data analysis

BMI and chaotic eating scores were not normally distributed, as assessed by Kolmogorov-Smirnov test (BMI:  $p = 0.004$ , chaotic eating of snacks,  $p = 0.00$ , chaotic eating of meals,  $p = 0.00$ ). Therefore, Spearman's rank-order correlations were used to assess pairwise comparisons with these variables. All other associations were assessed by deriving Pearson's correlation coefficients. To test the primary hypothesis, that chaotic eating would be positively associated with BMI, a multiple regression analysis was conducted. The interaction between gender and chaotic eating (snacks and meals) was tested by entering interaction terms in a regression model with BMI as the dependent variable. Gender was included as a covariate if the interaction between gender and chaotic eating was significantly associated with BMI. In a subsequent regression analysis, both chaotic eating of meals and snacks were entered as predictors in the same model, with BMI as the dependent variable. Age, gender and TFEQ subscale scores were also included as predictors in the regression analyses. Unstandardized betas ( $\beta$ ) from these models are presented. Residual P-P plots were inspected to assess whether the regression model fitted the non-normal data. Analyses were completed in SPSS version 23 (SPSS, Inc., Chicago, IL, USA).

### 5.4.3 Results

#### 5.4.3.1 Participant characteristics

There were 17 participants excluded from the analysis due to failure to complete the chaotic eating measures appropriately. The final dataset comprised 98 participants (55 women, 43 men), who had a mean age of 33.4 years  $\pm$  10.9 and a mean BMI of 27.5 kg/m<sup>2</sup>  $\pm$  5.1 (See Table 5.2). Of these, 30 had a BMI in the “normal” range, 40 were overweight and 28 were obese.

Table 5.2. Mean  $\pm$  SD and range for participant characteristics, number of snack and meal 30-min slots, frequency, and snack and meal chaotic eating index ( $N = 98$ ).

	Mean $\pm$ SD	Range (min-max)
Age (y)	33.4 $\pm$ 10.9	18 – 55
BMI (kg/m <sup>2</sup> )	27.6 $\pm$ 5.1	18.6 – 40.6
TFEQ- Disinhibition	8.1 $\pm$ 3.4	1.0 – 15.0
TFEQ- Restraint	8.5 $\pm$ 4.9	0.0 – 27.0
TFEQ- Hunger	7.2 $\pm$ 3.8	0.0 – 15.0
Number of Snack Timings (30-min time slots per week)	16.4 $\pm$ 9.5	7.0 – 63.0
Number of Meal Timings (30-min time slots per week)	19.7 $\pm$ 5.4	7.0 – 49.0
Snack Frequency (snacks per day)	3.8 $\pm$ 4.5	1.0 – 25.0
Meal Frequency (meals per day)	2.8 $\pm$ 0.9	1.0 – 7.0
Snack Chaotic Index (30-min time slots per snack)	2.3 $\pm$ 1.9	0.2 – 10.0
Meal Chaotic Index (30-min time slots per meal)	3.2 $\pm$ 2.5	0.5 – 12.5



#### 5.4.3.2 Correlations between BMI, chaotic eating, TFEQ, and age

The relationship between BMI and chaotic snack consumption was weak and not statistically significant,  $\rho = -0.11$ ,  $p = 0.30$ , as was the relationship between BMI and chaotic meal consumption,  $\rho = -0.01$ ,  $p = 0.95$ . There was little evidence that chaotic snack and meal consumption correlated with TFEQ-disinhibition or hunger (See Table 5.3). Chaotic snack consumption was negatively correlated with TFEQ-restraint. BMI was positively correlated with age, and with TFEQ-disinhibition and hunger scores, but not with dietary restraint (see Table 5.3).

Table 5.3. Spearman's ( $\rho$ ) and Pearson's ( $r$ ) correlations between BMI, snack and meal chaotic eating index, TFEQ-disinhibition hunger and restraint, and age from Study 6.

	BMI	Snack Chaotic Eating Index	Meal Chaotic Eating Index	TFEQ – Disinhibition	TFEQ – Restraint	TFEQ – Hunger	Age
BMI ( $\rho$ )		-0.11	-0.01	0.28**	.10	.27**	0.16
Snack Chaotic Eating Index ( $\rho$ )			0.02	-0.07	-.25*	-0.06	-0.20
Meal Chaotic Eating Index ( $\rho$ )				-0.04	-.02	-0.13	-0.03
TFEQ – Disinhibition ( $r$ )					0.10	0.67**	-0.23*

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TFEQ – Restraint ( <i>r</i> )	0.14	-0.24
TFEQ – Hunger ( <i>r</i> )		-0.14
Age ( <i>r</i> )		

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\*  $p < 0.05$

\*\*  $p < 0.001$

#### 5.4.3.3 Relationship between chaotic eating and BMI

There was little evidence for an interaction between gender and chaotic consumption of snacks,  $\beta = .06$ ,  $p = 0.83$ , or meals,  $\beta = -0.03$ ,  $p = 0.89$ . Therefore, gender was not included as a covariate in the subsequent analysis. In models adjusted for age and TFEQ subscales, evidence failed to support an association between BMI and chaotic meal consumption,  $\beta = -0.06$ ,  $p = 0.75$ , or chaotic snack consumption,  $\beta = -.05$ ,  $p = 0.87$ . The model predicted 15% of the variance in BMI,  $R^2 = 0.17$ ,  $F(6, 95) = 3.1$ ,  $p = 0.01$ . Despite the non-normal distribution of BMI, upon inspection of the distribution of residuals using P-P plots, the regression model was a good fit to the data. To summarise how chaotic eating relates to BMI for graphical purposes, ANCOVAs were used to derive model estimated marginal means and standard error of BMI at chaotic eating quartiles (snacks and meals), when TFEQ subscales and age were controlled for. The linear trends for chaotic eating quartiles (snacks and meals) are displayed in Figure 5.3.

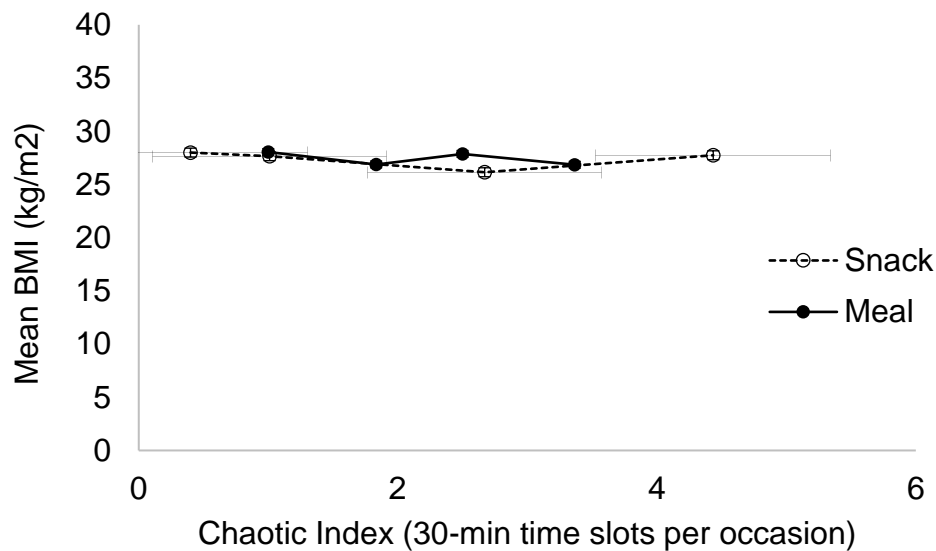


Figure 5.3. Relationship between BMI and chaotic snack and meal consumption for Study 6. ANCOVAs were used to derive model estimated marginal means and standard error of BMI at chaotic eating quartiles (snacks and meals), after controlling for age and scores on the TFEQ. Chaotic eating index scores were separated into four equal quartiles. Error bars represent  $\pm 1$  SEM.

#### 5.4.4 Interim discussion

This study used a novel index to assess chaotic eating, reflecting variability in the timing of meals and snacks. Against the hypothesis, there was little evidence for a relationship between BMI and chaotic eating. Chaotic eating of meals and snacks was not associated with TFEQ disinhibition or hunger, but chaotic consumption of snacks correlated with lower dietary restraint. Greater restrained eating was associated with less chaotic snacking, suggesting that attempts to limit dietary intake promote regularity. A secondary question relates to whether chaotic eating is associated with other dietary traits. Greater restrained eating was associated with less chaotic snacking, suggesting that attempts to limit dietary intake promote regularity. The validity and reliability of this current measure has not been assessed, though several limitations are suggested.

#### 5.4.4.1 *Methodological Issues*

One issue is that the terms 'snack' and 'meal' was not clearly defined to participants. The classification of meals and snacks may represent several aspects of eating patterns. Snack can be defined as the amount of food eaten, the type of food, frequency, time of day or eating not motivated by hunger (Gregori, Foltran, Ghidina, & Berchiolla, 2011). Conversely, snacking could simply be classified as any eating outside of main meals. The current literature lacks a unanimous definition of snacks and meals and, distinctions between a meal, a snack and a drink are ambiguous (Murakami & Livingstone, 2015). Studies typically use different classifications of snacks and meals (Gregori et al., 2011; Murakami & Livingstone, 2015). In both Studies 6 and 7, participants were asked to report their eating habits without providing clear definitions. It is likely that there were distinct differences in participants' subjective definitions of a snack and a meal. This lack of consensus about what constitutes a snack and a meal, could cause definitions to become self-defined, thus reducing the validity of the data. To ensure the most accurate self-reported eating habits in future studies, it is important to clearly distinguish between meals and snacks to participants.

An additional possibility is that our findings reflect an error or bias in self-reported eating habits. Assessing dietary behaviour using self-report questionnaires has been a longstanding problem in nutritional research (Beechy, Galpern, Petrone, & Das, 2012); people are prone to misreporting both their dietary intake and patterns (Berg et al., 2009; Macdiarmid & Blundell, 1998). As such, there is a concern about the impact of misreporting on the interpretation of our dietary data. Moreover, this bias is not randomly distributed within a population; evidence suggests that under-reporting is more prevalent in individuals who are overweight and obese (Macdiarmid & Blundell, 1998). If obese and overweight subgroups tended to under report their snack and meal chaotic eating, this would have skewed the results, thus reducing the validity of our findings. Hence, it cannot be concluded from Study 6 and 7 that there is no association between chaotic eating and BMI. A further limitation of the chaotic eating measures used in both studies is the lack of consistency

between the variability and frequency questions; irregular meal timings were measured for a typical week whereas eating frequency was measured for a typical day. This might explain the null findings, as the two measures do not reflect eating patterns across the same time scale, hence are limited in comparability. The hypothesis merits more robust data analyses to resolve these methodological issues. Thus, evidence for a relationship between BMI and chaotic eating was explored in Study 8, using data from diet-diaries, where misreporting of energy intake can be quantified.

### 5.5 **Study 8**

Based on the limitations of Studies 6 and 7, a different approach was taken for Study 8. Multi-day weighed diet diaries require participants to precisely weigh and prospectively record all food and beverages consumed, as well as the timing of consumption over several days. When compared to dietary recall interviews or food frequency questionnaires, 7 day weighed diet diaries are considered the gold standard. Weighed diaries avoid issues with relying upon participants' retrospective reporting or bias in the inaccurate estimation of food intake (Gersovitz, Madden, & Smiciklas-Wright, 1978; Johnson, 2002). Although diet diaries are also subject to underreporting (Trabulsi & Schoeller, 2001) and individual biases (Hebert, Clemow, Pbert, Ockene, & Ockene, 1995), they are shown to provide a reliable estimate of food intake, when compared to intake measured objectively using urinary biomarkers (Bingham et al., 1997).

Several studies have used diet diaries or 24hr recall interviews to assess eating frequency (Drummond et al., 1998; Duval et al., 2008; Kant, Schatzkin, Graubard, & Ballard-Barbash, 1995; Ruidavets et al., 2002), eating patterns (Aparicio et al., 2017; Berg et al., 2009; Samuelson, 2000; Summerbell, Moody, Shanks, Stock, & Geissler, 1996) and day-to-day irregularity of energy intake (Pot et al., 2014, 2016). However, to our knowledge no study has used diet diaries to assess variability in the *timing* of eating occasions (chaotic eating).

The aim of the current study was to analyse the relationship between BMI and chaotic consumption of meals and snacks, in a representative sample of UK adults, using seven-day weighed diet diaries from the NDNS. Using the same methods as Study 7, a separate meal and snack 'chaotic eating index' was derived from the number of different 30-minute snack- or meal-timings across the week, divided by the frequency of these eating events across the week. It was hypothesised that chaotic eating would be associated with high BMI. In addition, associations between BMI, chaotic eating and energy intake were assessed. It was predicted that chaotic eating would be associated with total energy intake. To explore how chaotic eating relates to eating behaviours that might promote or modify weight gain, measures of emotional, external and restrained eating drawn from the subsections of the DEBQ were included. Additionally, total energy intake was explored as a mediator of the relationship between chaotic eating and BMI.

### *5.5.1 Methods – Study 8*

#### *5.5.1.1 Participants*

The NDNS 2000 is a cross-sectional survey of a nationally representative sample of UK adults (aged 19–64 years). A multistage random probability design was used to selected people living in private households across the UK. The survey asked questions focused on diet, nutritional status and nutrient intake. Specific details of the design and data collection can be found elsewhere (Survey, 2001). In brief, trained interviewers asked participants to complete a 7-day weighed diet diary. All interviews were conducted over a 12-month period in 2000/2001. Ethical approval for the NDNS was obtained from the Multi-Centre Research Ethics Committee and National Health Service Local Research Ethics Committee covering each of the 152 postcodes areas in the sample. Data were accessed from the UK data archive (Survey, 2001). Participants provided information, including height and weight. The adult respondents of the NDNS were 19–64 years old and 94% of the sample was White British.

### *5.5.1.2 Classifying intake occasions as meals and snacks*

Following previous methods (Olea López & Johnson, 2016), intake occasions were classified as meals using food group combinations (Macdiarmid et al., 2009). All NDNS food groups were classified into meal food lists, based on frequently consumed foods during meals (Chamontin, Pretzer, & Booth, 2003; Hartmann, Siegrist, & van der Horst, 2013; Macdiarmid et al., 2009). For example, a pizza would be on the meal list, whereas a banana would be on the snack list and a smoothie would be on the drink list. Intake occasions were classified as a meal if all food items were from the meal list, or if at least one food item was from the meal-list, combined with other items from either the snack or drink list. If only two items were reported, and one was a meal food and one was a snack, e.g. bread and butter, the occasion was classified as a snack. Intake occasions were classified as a snack if all items in an occasion were from the snack list or if an occasion contained two items, one from the meal-list and one from the snack-list. Drinks on their own and supplements were not considered as intake occasions for this study.

### *5.5.1.3 Calculating chaotic eating*

To measure chaotic eating, the variability in the number of different meal timings across the week was calculated. Initially, mirroring Study 6, the timings of meals were separated into 30-minute time slots. For example, if a meal was eaten at 9:08, they were classified as 9:00-9:30; if a meal was eaten at 9.42, this was classified as 9:30-10:00. For each participant, the number of 30-minute periods in which they ate a meal across the seven days was totalled. Meal frequency was calculated from the mean number of meal occasions per day. Following Study 6, a meal chaotic eating index was computed by dividing the number of meal timings by the meal frequency. A higher chaotic eating index represents greater variability in the number of times a meal might be eaten, and therefore a more chaotic pattern of eating. A snack chaotic eating index was also calculated, based on the timing and daily frequency of snacks.

To further explore chaotic eating timing using a different method, the variation in the IMI between meals across the week for each participant was computed. Using the time of each meal in minutes since midnight, the time between adjacent eating occasions within a day was calculated. Based on multiple time differences between eating occasions each day, SD in the lengths of the IMIs across the seven days was then calculated. It was hypothesised that high variation in IMIs would also reflect chaotic eating of meals and expected high correlations between the two measures.

#### *5.5.1.4 Exclusion criteria*

The initial sample comprised 2251 diary records, however only 1724 participants completed the full dietary record. From these cases, following previous research (Olea López & Johnson, 2016) records with missing DEBQ (n = 92) scores and anthropometric data (n = 186) were excluded. In addition, dieters (those who confirmed they were dieting to lose weight during the survey, n = 271) were excluded to avoid identifying eating patterns that were not representative of typical behaviours (Olea López & Johnson, 2016). The final sample size comprised 1175 participants; 557 men and 618 women.

#### *5.5.1.5 Questionnaires*

Prior to completing diet diaries, participants completed the DEBQ. The 33-item questionnaire assesses three subscales; emotional (e.g. 'Do you have a desire to eat when you are feeling lonely', restrained (e.g. 'Do you try to eat less at mealtimes than you would like to eat?'), and external eating (e.g. 'If you see others eating, do you also have the desire to eat?'), using a 5-point Likert scale. The DEBQ has high internal consistency, and provides reliable measures for individuals with BMIs in the "normal" range, and people with obesity (Bohrer, Forbush, & Hunt, 2015). This measure differs slightly from the TFEQ, as it separates aspects of disinhibited eating by differentially assessing external and emotional eating. However, both questionnaires measure restrained eating and demonstrate acceptable internal consistency (Bohrer et al., 2015).



### 5.5.1.6 Covariates

Self-reported highest education qualification was used as a proxy for socioeconomic status. Following previous analyses (Olea López & Johnson, 2016), the extent to which the association between chaotic eating and BMI is mediated by increased total energy intake or confounded by under-reporting was assessed. To calculate average daily intake for each participant, the number of calories reported across the seven days was summed and divided by the number of days. Physical activity diaries were completed, in which participants reported all activities and their duration for the same 7-days of the dietary diaries. These were used to calculate metabolic equivalent-hours per week (METs; Survey, 2001), which were converted to physical activity level (PAL) using standard equations (Trumbo, Schlicker, Yates, & Poos, 2002) that define participants as sedentary, low active, active or very active. PALs were defined from number of minutes of moderate to vigorous exercise across the week. Estimated energy requirements were calculated for each participant based on sex, age, weight, height and PAL. To measure under-reporting, the total energy intake of all foods and drinks (TEI) was divided by the estimated energy requirements (EER), TEI/EER, which, assuming neutral energy balance, should equal 1.0. To control for random error in the estimation of energy intake and expenditure, the confidence limits of agreement for TEI/EER using variation coefficients were calculated. On this basis, participants were defined as either under-reporters (TEI/EER < 0.71) or over-reporters (TEI/EER > 1.29; Rennie, Coward, & Jebb, 2007). In addition, the total energy intake per day of meals and snacks was separately calculated.

### 5.5.2 Data analyses

Snack and meal chaotic eating index scores and BMI were not normally distributed, as assessed by Kolmogorov-Smirnov test (BMI:  $p = 0.00$ , chaotic eating of snacks:  $p = 0.00$ , chaotic eating of meals:  $p = 0.01$ ). Therefore, Spearman's correlations were used to assess the relationships between BMI and chaotic eating of meals and snacks. Pearson's

correlations were used to assess parametric relationships between total energy intake, DEBQ subscale scores, and age.

To test our primary hypothesis, a multiple linear regression was performed using meal and snack chaotic eating indices as independent variables and BMI as the dependent variable. To control for age, gender, socioeconomic status, physical activity levels, and DEBQ-subscale scores these variables were included (Model 1). To determine whether total energy intake mediated an association between BMI and chaotic eating, total energy intake was also included in a second model (Model 2). It was predicted that the association between chaotic eating and BMI would no longer be significant when total energy intake was included as a mediator. Finally, under-reporting category was added to a third model, alongside other predictors from Model 3 (Model 3). Unstandardized betas ( $\beta$ ) from all three models are presented. Thirty-seven participants had missing data for under-reporting, so were removed from Model 3. Analyses were completed in SPSS version 23 (SPSS, Inc., Chicago, IL, USA).

### *5.5.3 Results*

#### *5.5.3.1 Participant characteristics*

When classified by BMI groups, the final sample resulted in 24 underweight, 510 lean, 426 overweight, and 215 obese participants. Participants were defined as underweight ( $\text{BMI} < 18\text{kg/m}^2$ ), lean ( $18\text{kg/m}^2 < \text{BMI} < 25\text{kg/m}^2$ ), overweight ( $\geq 25\text{kg/m}^2$  &  $\text{BMI} < 30\text{kg/m}^2$ ) and obese ( $\text{BMI} \geq 30\text{kg/m}^2$ ). 217 participants were classified as under-reporters of energy intake and 921 participants were classified as plausible reporters. 242 had a degree or equivalent (21%), 166 914.1% had higher education below degree level, 116 (9.9%) had A level or equivalent, 356 (30.3%) had GCSE grades A-C or equivalent, 67 (5.7%) had GCSE grades D-E or equivalent, 41 (3.5%) has other qualifications and 187 (15.9%) had no qualifications. See Table 5.4 for participant characteristics.

Table 5.4. Participant characteristics ( $N = 1175$ ; 557 men and 618 women), average daily caloric intake of meals and snacks, moderate physical activity levels (mins), meal and meal frequency, number of 30-min meal and snack timings, and chaotic eating index scores.

Means are shown in combination with associated standard deviation and range.

	Mean $\pm$ SD	Range (min-max)
Age (y)	41.9 $\pm$ 12.0	19.0 – 64.0
BMI (kg/m <sup>2</sup> )	26.3 $\pm$ 5.1	15.9 – 67.3
DEBQ- External Eating	2.6 $\pm$ 0.6	1.0 – 4.6
DEBQ- Emotional Eating	1.8 $\pm$ 0.7	1.0 – 5.0
DEBQ- Restraint	2.2 $\pm$ 0.9	1.0 – 5.0
Average Meal Energy Intake (kcal per day)	1357.8 $\pm$ 472.7	182.2 – 3696.4
Average Snack Energy Intake (kcal per day)	261.1 $\pm$ 201.1	0.0 – 1464.2
MVPA Levels (minutes)	95.0 $\pm$ 140.5	0.0 – 747.1
Number of Meal Timings (30-min time slots per week)	10.4 $\pm$ 3.0	1.0 – 22.0
Meal Frequency (meals per day)	2.5 $\pm$ 0.7	0.4 – 6.0
Meal Chaotic Eating Index (30-min time slots per meal)	0.61 $\pm$ 0.14	0.2 – 1.0
Number of Snack Timings (30-min time slots per week)	11.9 $\pm$ 6.2	1.0 – 35.0
Snack Frequency (snacks per day)	2.5 $\pm$ 1.6	0.1 – 16.1
Snack Chaotic Eating Index (30-min time slots per snack)	5.4 $\pm$ 1.4	1.3 – 11.7

DEBQ=Dutch Eating Behaviour Questionnaire; MVPA=Moderate to vigorous physical activity; SD=Standard deviation

### 5.5.3.2 *Correlations between BMI, chaotic eating, total energy intake and DEBQ subscales*

There was little evidence for a correlation between BMI and chaotic eating of meals and snacks (see Table 5.5). Chaotic eating of both meals and snacks was inversely correlated with total energy intake. There was evidence that chaotic eating of meals was positively correlated with emotional and external eating scores, and negatively correlated with restrained eating. Chaotic eating of snacks did not correlate with any DEBQ subscales. Meal chaotic eating index scores significantly correlated with the SD of IMI, suggesting both measures reflect similar chaotic and irregular meal timings. BMI was positively correlated with total average energy intake, social class, restrained eating, emotional eating, and age (see Table 5.5).

### 5.5.3.3 *Relationship between chaotic eating and BMI*

In multiple linear regression models adjusted for age, gender, social class, physical activity levels and DEBQ subscales (Model 1), there was little evidence for an association between BMI and chaotic eating of meals,  $\beta = 0.08$ ,  $p = 0.62$ , or snacks,  $\beta = 0.13$ ,  $p = 0.19$ . After adjusting for total energy intake (Model 2), the association between BMI and chaotic eating became slightly stronger but statistical evidence remained weak, meals:  $\beta = 0.15$ ,  $p = 0.34$ ; snacks:  $\beta = 0.16$ ,  $p = 0.12$ . Adjusting for under-reporting (Model 3), the association with chaotic eating remained insignificant, meals:  $\beta = 0.16$ ,  $p = 0.28$ ; snacks:  $\beta = 0.15$ ,  $p = 0.13$ . The results of the regression indicated that Model 3 explained 16% of the variance in BMI,  $R^2 = 0.15$ ,  $F(11,1137) = 20.03$ ,  $p = 0.001$ . No evidence of a relationship between BMI and chaotic meal or snack consumption was observed<sup>4</sup>. See Table 5.6 for regression coefficients of each model. Despite the non-normal distribution of BMI, upon inspection of

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<sup>4</sup> Similar results were observed when timings were binned in 1-hour intervals ( $\beta = 0.014$ ,  $p = 0.83$ ).

the distribution of residuals using P-P plots, the regression model was a good fit to the data. For graphical purposes, ANCOVAs were used to derive Model 4 estimated marginal means and standard error of BMI at equal chaotic eating quintiles, when DEBQ subscales, age, total energy intake and under-reporting were controlled for (See Figure 5.4).

Table 5.5. Spearman's (*rho*) and Pearson's (*r*) correlations between BMI, chaotic eating indices, total daily intake, DEBQ, age, social class and physical activity from the NDNS data.

	Meal Chaotic Eating Index	Snack Chaotic Eating Index	Average Energy Intake	DEBQ - External Eating	DEBQ - Emotional Eating	DEBQ - Restraine d Eating	Age	Education Level	MVPA (mins)
BMI ( <i>rho</i> )	-0.05	-0.02	0.15**	-0.02	0.11**	0.22**	0.23**	0.10**	0.03
Meal Chaotic Eating Index ( <i>rho</i> )		0.13**	-0.27**	0.11**	0.11**	-0.06*	-0.28**	0.01	0.02
Snack Chaotic Eating Index ( <i>rho</i> )			-0.08*	0.02	-0.01	-0.01	0.02	-0.06	-0.03
Total Energy Intake ( <i>r</i> )				0.01**	-0.11*	-0.27**	0.05	-0.15**	0.19**
DEBQ – External Eating ( <i>r</i> )					0.49**	0.18**	-0.30**	-0.14**	-0.01
DEBQ – Emotional Eating ( <i>r</i> )						0.29**	-0.17**	-0.07*	-0.09**

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DEBQ – Restrained Eating	0.13**	-0.11**	-0.05
( <i>r</i> )			
Age ( <i>r</i> )		0.20**	-0.11**
Education Level;( <i>r</i> )			0.14**

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\* =  $p < 0.05$ , \*\* =  $p < 0.001$

DEBQ=Dutch Eating Behaviour Questionnaire; MVPA=Moderate to vigorous physical activity

Table 5.6. Regression coefficients with r-squared values derived from each model of the multiple regression analysis

Independent variable (IV)	Model 1 <sup>a</sup> Adjusted for age, gender, DEBQ subscales, physical activity and social class			Model 2 <sup>b</sup> Adjusted for age, gender, DEBQ subscales, physical activity, social class and energy intake			Model 3 <sup>c</sup> Adjusted for age, gender, DEBQ subscales, physical activity, social class, energy intake and misreporting		
	$\beta$	R <sup>2</sup>	$p$	$\beta$	R <sup>2</sup>	$p$	$\beta$	R <sup>2</sup>	$p$
Chaotic eating (meals)	0.08	0.11	0.62	0.15	0.12	0.34	0.16	0.15	0.28
Chaotic eating (snacks)	0.13	0.11	0.19	0.16	0.12	0.12	0.15	0.15	0.13
Age	0.09	0.11	0.00	0.09	0.12	0.00	0.10	0.15	0.00
Gender	1.83	0.11	0.00	1.27	0.12	0.00	0.23	0.15	0.56
DEBQ-emotional eating	1.55	0.11	0.00	1.52	0.12	0.00	1.34	0.15	0.00
DEBQ-external eating	-0.67	0.11	0.03	-0.83	0.12	0.01	-0.72	0.15	0.02
DEBQ- restraint	0.73	0.11	0.00	0.78	0.12	0.00	0.69	0.15	0.00
Social class	0.26	0.11	0.02	0.28	0.12	0.11	0.30	0.15	0.01
Physical activity	0.00	0.11	0.26	0.00	0.12	0.45	0.00	0.15	0.66
Energy intake	n/a	n/a	n/a	0.00	0.12	0.00	0.00	0.15	0.00
Misreporting	n/a	n/a	n/a	n/a	n/a	n/a	2.71	0.15	0.00

n/a = not applicable, DEBQ = Dutch Eating behaviour Questionnaire



<sup>a</sup> Adjusted for age, gender, DEBQ subscales, physical activity and social class

<sup>b</sup> Adjusted for age, gender, DEBQ subscales, physical activity, social class and energy intake

<sup>c</sup> Adjusted for age, gender, DEBQ subscales, physical activity, social class, energy intake and misreporting

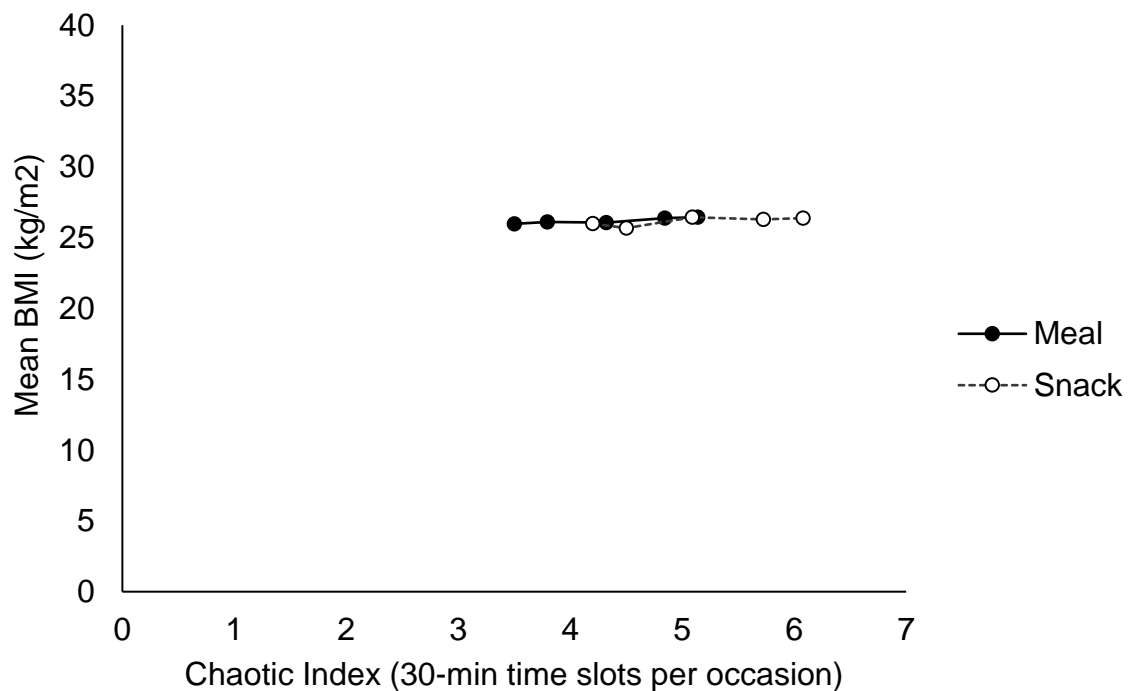


Figure 5.4. Relationship between BMI and chaotic eating of meals and snacks for Study 8. ANCOVAs were used to derive Model 3 estimated marginal means and standard error of BMI at chaotic eating quartiles, after controlling for DEBQ subscales, age, gender, socioeconomic status, physical activity levels, total energy intake and under-reporting. Chaotic eating indices were separated into five equal quintiles.

## 5.6 General discussion

In this chapter a novel measure was used to determine the relationship between BMI and chaotic eating, defined by variability in the timing of eating occasions. In Studies 6 and 7

there was no association between chaotic consumption of meals and snacks, based on self-reported timings, with BMI. In Study 8, a measure of chaotic eating was derived from seven-day, weighed diet diaries. Contrary to the hypothesis, there was little evidence for an association between BMI and chaotic consumption of meals or snacks, even when controlling for eating frequency, total energy intake and under-reporting. Similarly, variation in the IMI across the week, which may also reflect chaotic eating, was not significantly associated with BMI.

In contrast to the hypothesis that chaotic eating would be associated with high BMI, the findings from Studies 6 and 7 suggest that variability in the timing of meals is not associated with high BMI. Moreover, in Study 8, chaotic eating of meals was associated with reduced total energy intake. The results suggest that chaotic eating does not promote weight gain and may even reduce food intake. These findings could have significant implications for dietary recommendations for healthy eating and weight loss (Canada, 2017; Gov.au, 2012; NHS, 2017) and cognitive behavioural therapies for obesity (Burton & Stice, 2006; Graham & Reynolds, 2013; Palavras et al., 2015). The approach used to assess chaotic eating did not support an association with variability in meal timings and high BMI. Broadly, there was little evidence for an association between chaotic eating and BMI, which is relevant to guidelines that recommend regularity in meal and snack timings for weight loss. More robust evidence is required to inform dietary guidelines to endorse regular meal timings. In the future, a randomised controlled trial is recommended to evaluate this guidance.

Irregular eating patterns have been previously researched as a factor associated with eating behaviours related to BMI and obesity. Studies vary in which aspect of eating architecture is irregular (Alhussain et al., 2016; Berkey et al., 2003; Farshchi et al., 2004a, 2004b, 2005a; Kagamimori et al., 1999; Lehto et al., 2011; Pot et al., 2014, 2016; Rodrigues et al., 2016; Sierra-Johnson et al., 2008; Takahashi et al., 1999; Yang et al., 2006), irregular day-to-day eating frequency, self-reported irregular eating, or variability in energy intake per eating occasion have been associated with higher BMI, increased food intake, metabolic

syndrome and a reduced insulin response. However, it is regularity in the timings of eating occasions that is typically recommended for healthy eating or weight loss (Canada, 2017; Gov.au, 2012; NHS, 2017). As it stands, the evidence for an association between chaotic eating and BMI is weak. One possibility is that the various definitions of irregularity have become conflated, leading to dietary advice that lacks empirical support. It is essential that future studies distinguish between these various manifestations of regularity to gain a more nuanced understanding of how irregular meal timings relate to eating behaviour and weight gain.

Nevertheless, short-term highly controlled experiments (Jakubowicz et al., 2013; Morgan et al., 2012) and more ecologically valid, but cross-sectional, observational studies (Eicher-Miller et al., 2016; Leech et al., 2017) have shown that temporal eating patterns and the timing of meals may influence weight regulation (Jakubowicz et al., 2013), health outcomes (Morgan et al., 2012), diet quality and adiposity (Eicher-Miller et al., 2016; Leech et al., 2017). However, these are a weak form of evidence on which to base any guidelines. Previous intervention studies that assess the benefits of regular meal timings have not measured weight loss, and have small sample sizes (Farshchi et al., 2005a). The proposition that regular meal timings promote weight loss currently lacks support from long-term trials in free-living humans' prospective observations. In the future, it is important that a randomised controlled trial is conducted to evaluate the efficacy of this guidance, in which weight loss is monitored while participants are prescribed structured, regular, eating occasions.

However, it is also possible that relationship between BMI and chaotic eating is not linear, but quadratic, and thus was not captured by the linear analysis,. Chaotic eating might reflect both beneficial and harmful strategies. For instance, a person with a high chaotic eating score might be an intuitive eater, who tends to eat in response to their hunger and fullness signal, and thus have a low BMI. Similarly, a high score could also reflect the tendency to binge eat or snack, which are more likely to be associated with a high BMI. Thus, the current null findings might not reflect the true relationship. Further analyses should

assess a potential quadratic relationship between chaotic eating and BMI to capture complexities in the association between chaotic eating and BMI.

Although there was little evidence to suggest that people with a high BMI eat more chaotically, regular meal timings may be important when considered in the context of IMI sensitivity. It was reported in Study 1 (Chapter 2) and Study 2 (Chapter 3) that individuals with a high BMI are less sensitive to the certainty and length of an IMI. It is also likely that IMI sensitivity varies in people who eat chaotically; some may be less sensitive to information about IMIs than others. One proposition is that the association between chaotic eating and BMI depends on how sensitive an individual is to future meal timings. For example, a person who eats at irregular meal timings, and is less sensitive to IMIs, might not adjust their portion sizes when the length of the IMIs changes from day-to-day, and consequentially overeat. Conversely, a person who eats at irregular meal timings, and is more sensitive to IMIs, might be more likely to adjust their portion sizes with the varying lengths of day-to-day IMIs. Therefore, it could be possible that a chaotic eating pattern promotes overeating, and weight gain, in individuals who are less sensitive to future meal timings. Understanding how differences in IMI sensitivity manifest in a chaotic eating pattern could help to tease apart the effects of chaotic eating on food intake and BMI, which were potentially overlooked in the studies presented in Studies 3, 4 and 5 (Chapter 4). Although this was beyond the scope of the thesis, subsequent studies could assess whether IMI sensitivity influences how people respond to a chaotic eating pattern and explore potential consequences for food intake and BMI.

It is important to note that the current measure of chaotic eating did not differentiate certain or uncertain meal timings. Findings from Study 1 and 2 (Chapter 2 and 3) demonstrate that delay discounting may be more likely to manifest in portion size decisions when meal timings are uncertain. Thus, a chaotic eating pattern in which meal timings are uncertain might influence food intake and weight gain differently from a chaotic eating

pattern in which meal timings are certain. In the future, chaotic eating measures should distinguish between irregular eating in the presence or absence of uncertainty.

A secondary question relates to whether chaotic eating is associated with other dietary traits. In Study 7, only chaotic eating of snacks was correlated with low dietary restraint, whereas, in Study 8, only chaotic eating of meals was associated with dietary restraint. This suggests that individuals who eat at irregular day-to-day timings are less likely to restrict their eating behaviours. This suggests that those who eat chaotically may eat more intuitively, in response to hunger and fullness cues, whereas less chaotic individuals might be more restrictive and only eat at certain times. However, these results are inconsistent and require further research.

In Study 8, there was little evidence that chaotic eating of snacks was related to emotional or external eating. Conversely, high emotional and external eating were associated with higher chaotic eating of meals and high BMI, suggesting that individuals who eat at more variable meal timings might have a greater tendency to eat in response to external or emotional triggers. However, chaotic eating of meals was associated with reduced energy intake. Given these paradoxical findings, it is difficult to draw firm conclusions about specific dietary styles that might promote chaotic eating or influence food intake. Similarly, chaotic eating was not associated with sample characteristics such as social class or physical activity levels but did correlate with BMI. Further research is required to explore how these individual differences might interact with a chaotic eating pattern.

It is important to note that the results from Studies 6 and 7 might reflect misreporting. The strengths and weaknesses of self-report dietary assessment methods are well documented (Beechy et al., 2012; Johnson, 2002). One issue is that participants have shown to be self-conscious of judgement, and misreport their diet for fear of appearing unhealthy (Price, Paul, Cole, & Wadsworth, 1997). This is particularly problematic when assessing obese and overweight individuals, where misreporting is known to be more

prevalent (Lichtman, 1992; Prentice et al., 1986), It is possible that individuals with a high BMI are more aware of health-related criticisms and so report what they believe to be a healthier diet to avoid judgement (Mertz, 1991). In addition, evidence suggests snacks are more likely to be under-reported, potentially reflecting an issue around memory or disinhibition while eating. Nevertheless, Study 8 was designed to address issues with self-report methods by using seven-day weighed diaries (widely accepted as a gold standard of dietary assessment) and specifically quantifying under-reporting.

The use of National representative sample means that the associations observed are reflective of the general UK adult population (Olea López & Johnson, 2016). Nevertheless, it is argued that novel methods that do not rely on self-report to measure dietary patterns should be employed. Moving away from self-report will enable eating behaviour to be captured in a naturalistic way to gauge a valid and reliable measure of chaotic eating. Technology has been developed to assess dietary patterns more accurately and objectively. Small cameras or recording devices have been employed, which involve participants photographing all eating occasions (Higgins et al., 2009; Six et al., 2010). However, these recording devices have failed to produce more accurate food intake reports than food diaries. Novel advances, such as the Microsoft SenseCam (Hodges, 2006; Sabinsky, Toft, Andersen, & Tetens, 2013), that automatically takes pictures of food and logs eating occasions have been designed to decrease misreporting. In addition, wrist work smart watches have been established to record information about timing and frequency of eating occasions (Dong, Hoover, Scisco, & Muth, 2012). To validly assess whether individuals with a high BMI eat more chaotically, future studies could implement such wearable technology to validly measure variability in eating timings.

The use of a large sample with a wide range of BMIs and social classes is an additional strength of Study 8, although the data was collected from 2000-2001 so may not reflect present-day meal patterns (Olea López & Johnson, 2016). The chaotic eating measure does not distinguish between different meals types (e.g. breakfast, lunch or dinner);

future research could explore how the regularity at specific times of day might impact caloric intake and BMI. Finally, all studies presented in this chapter are cross-sectional, which has a limited ability to draw causal conclusions and as with any observational study the possibility of unmeasured confounders cannot be ruled out.

### *5.7 Chapter summary*

The findings from Studies 1 (Chapter 2), 2 (Chapter 3), 3, 4 and 5 (Chapter 4) failed to support the hypothesis that uncertainty about the timing of future meals significantly increases portion size selection. This led to doubts as to whether eating at irregular times of day, in which meal timings are uncertain, influences food intake, or consequential weight gain. Despite weight loss recommendations that regular, structured eating timings should be adhered to, findings from three studies failed to show a relationship between chaotic eating and BMI. It is argued that, while regular eating timings may be an important factor in weight loss, such advice is currently lacking support and there is limited evidence that regular meal or snack timings should be recommended. Nevertheless, these findings should be replicated using a more rigorous design, such as a randomised controlled trial, to evaluate the efficacy of this guidance.

### *5.8 Acknowledgements*

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## 6 Chapter 6. Study 9.

### **Impulsivity and nutritional state: Fasting increases delay discounting of food but does not affect probability or delay discounting of money**

The author was responsible for the analysis, interpretation and write up of the data reported below. Sarah Ali and Dana Smith were responsible for the design and data collection. Tony Goldstone supervised this study.

#### *6.1 Chapter Summary*

In the previous Chapters (Study 1, Chapter 2 and Study 2, Chapter 3), the association between delay discounting and sensitivity to future meal timings when making portion size decisions were assessed. The findings from Study 1 (Chapter 2) showed that steep monetary delay discounting was associated with reduced IMI sensitivity, and moderated the relationships between reduced IMI sensitivity and high BMI. The results from Study 2 (Chapter 3) did not support a relationship between monetary delay discounting and IMI sensitivity, though both independently predicted BMI in a sample with a wide BMI range. The primary aim of this chapter is to test the hypothesis that hunger increases delay and probability discounting. In addition, this chapter will explore questions raised in Study 1 (Chapter 2) and Study 2 (Chapter 3), as to whether individuals who tend to discount food rewards are also more likely to discount monetary rewards.

The aims of this chapter are:

1. To assess how fasting influences both delay and probability discounting of different reward categories.
2. To compare differences between money and food discounting, and between HED and LED foods.



## 6.2 Introduction

Impulsivity is a multifaceted construct that is commonly associated with obesity (Evenden, 1999; Whiteside & Lynam, 2016). In particular, discounting is a dimension of impulsivity that has received considerable attention (Barlow et al., 2016). Delay discounting describes the tendency to choose a smaller, immediate reward over a larger, delayed reward (Odum, 2011). Steep delay discounting is indicative of an individual's inability to consider the future and to delay gratification. Delay discounting of both food and money has been linked with increased food intake, unhealthy diet, overweight, obesity and binge eating disorder (Barlow et al., 2016). Conversely, probability discounting provides an index of an individual's response to uncertainty; a person who is risk averse will choose a relatively small certain reward over a larger, but less probable, reward (Rachlin, Raineri, & Cross, 1991). Steep probability discounting represents risk-averse behaviour (Green & Myerson, 2010). More risk aversion, i.e. taking less risks, towards money and food, in probability discounting tasks is associated with high BMI and obesity in some studies (Eisenstein, Gredysa, Antenor-Dorsey, et al., 2015; Hendrickson & Rasmussen, 2013; Lawyer et al., 2015; Rasmussen et al., 2010), but not others (Bickel et al., 2014).

There is debate as to whether these constructs are state-dependent. Hunger has been shown to induce impulsive behaviour. In one study, people acted more impulsively to money when hungry (Sellitto & di Pellegrino, 2014). One possibility is that hunger motivates participants to focus on their immediate needs, causing steeper discounting. However, few studies have manipulated nutritional state, and those that have present mixed results (see Table 6.1). Hunger has been shown to cause people to make less healthy choices and exhibit less self-control (Cheung, 2017). One study reported that impulsive people purchased more hypothetical food when in a state of hunger (Nederkoorn, Guerrieri, Havermans, Roefs, & Jansen, 2009). This suggests that the expression of impulsivity is influenced by nutritional state and, moreover, that dietary decisions are compromised when fasted. Similarly, in a within-subjects study, participants exhibited greater delay monetary

discounting after acute fasting (Bartholdy, Cheng, Schmidt, Campbell, & O'Daly, 2016). Conversely, in a between-subjects design (de Ridder, Kroese, Adriaanse, & Evers, 2014), little evidence was found for an effect of nutritional state on trait impulsivity (measured using the Barratt Impulsivity Scale), and monetary delay discounting decreased after fasting. Similarly, a within-subjects study that assessed the effects of blood glucose levels on monetary delay discounting by manipulating nutritional state (euglycemic vs. hypoglycemic states), failed to show an effect of blood glucose concentration on monetary delay discounting or food intake (Klement et al., 2018). Clearly, the evidence that delay discounting is influenced by hunger is mixed and requires further investigation.

Similarly, risk preferences appear to be sensitive to nutritional state. Non-human animals become less risk-seeking in food foraging tasks when hungry (Caraco, 1981; Caraco et al., 1990). In humans, fasting has been shown to reduce risky choices in a Lottery Choice Task (Symmonds, Emmanuel, Drew, Batterham, & Dolan, 2010) and reduce risk aversion in the Iowa Gambling Task, (de Ridder et al., 2014). Together, these findings suggest that hunger may counterintuitively increase risk aversion, i.e. reduce risk taking. However, no effect of hunger was found on people's willingness to take risks in obtain food in a gambling task (Festjens, 2018).

Table 6.1. Summary of impulsivity studies manipulating nutritional state. The design, task, commodity being discounted, and findings are presented.

Authors	Design	Task	Commodities	Results
<i>(a) Delay discounting</i>				
(Nederkoorn et al., 2009)	Between-subjects: fasted and fed groups	Response inhibition and food intake	Food	Impulsive people ate more food and purchased more

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		Food purchasing in virtual supermarket		hypothetical food when hungry
(Cameron, Goldfield, Finlayson, Blundell, & Doucet, 2014)	Between subjects: fasted and fed groups	Relative- reinforcing value progressive ratio task  Leeds food preference questionnaire (LFPQ; Explicit 'liking' and 'wanting').	Food	Increased relative reinforcing value of food and hedonic ratings of food when fasted
(de Ridder et al., 2014) - Experiment 1	Between- subjects: fasted and fed groups	Monetary delay discounting task	Money	Reduced monetary delay discounting
(Bartholdy et al., 2016)	Within-subjects: fasted and fed conditions	Monetary delay discounting task proactive inhibition task Stop signal task	Money	Greater delay discounting after fasting Improved inhibitory control after fasting

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(Klement et al., 2018)	Within-subjects: hypoglycemic vs euglycemic	Monetary delay discounting task	Money	No effect of blood glucose levels on delay discounting
<i>(b) Probability discounting</i>				
(Symmonds et al., 2010)	Within subjects: fasted, immediately post-meal and 60mins post-meal conditions	Multiple paired lottery choice task	Money	Risk aversion increased immediately after eating at 60mins post meal
(de Ridder et al., 2014) - Experiment 2	Between-subjects	Iowa gambling task (IGT) Size perception of food Balloon analogue risk task (BART)	Money and food	Fasting increased advantageous choices in the Iowa Gambling Task and increased size perceptions of food, but did not affect willingness to take risks in a BART (de Ridder et al., 2014).
(Festjens, 2018)	Between subjects: high	Gambling task and dice game	Money and food	Hunger had little effect on

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hunger (4hour  
fast) and low  
hunger (1hour  
fast)

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risk aversion to  
food or money

A possible explanation for these inconsistent findings is that the behavioural manifestations of impulsivity are multifaceted (Green & Myerson, 2013). Thus, it is important to consider the independent effects of hunger on different dimensions of impulsivity. Limited studies have specifically assessed how nutritional state influences both delay and probability discounting. The current study aimed to address this question by comparing performance on discounting tasks when participants were both fasted and fed. It is thought that hunger would motivate participants to focus on their immediate needs, causing steeper delay discounting. Given previous findings, it is hypothesised that hunger would increase delay discounting (Bartholdy et al., 2016; Nederkoorn et al., 2009) and increase risk aversion (de Ridder et al., 2014; Symmonds et al., 2010).

Additionally, previous studies have not comprehensively examined the effects of fasting on different categories of food, e.g. HED and LED food and money. Typically, tasks use monetary rewards to measure discounting (Critchfield & Kollins, 2001), although studies have begun to assess food-specific discounting (Amlung et al., 2016). There is evidence to suggest that not all rewards are discounted equally (Baker et al., 2003); food has shown to be discounted at a higher rate than money (Odum et al., 2006), potentially because food is a perishable, primary reinforcer, so might have a higher reward value, and be discounted at a higher rate compared to non-perishable, non-consumable secondary reinforcers (Charlton & Fantino, 2008). It is still unclear as to whether monetary and dietary discounting are independent or related traits. The results from Study 1 (Chapter 2) suggest that delay discounting of money is associated with delay discounting of future meal timings, whereas the findings from Study 2 (Chapter 3) suggest that these are independent variables.

The interaction between hunger, discounting rates and different rewards has not yet been investigated. In this study, the aim was to explore the differential effects of fasting on money, HED food and LED food. It has been shown that fasting increases participants' perceptions of the relative reinforcing value of snack foods and explicit liking and wanting of foods (Cameron et al., 2014). It is reasoned that, fasting will have a more direct influence on the value of food, rather than money. As such, it is predicted that hunger will be more likely to influence discounting of food, compared to money.

Similarly, an aim of the study was to compare the differences in the effects of fasting on HED, compared to LED, food. Findings from Study 2 (Chapter 3) showed that there was no difference in future thinking about HED vs. LED portion sizes in response to certain IMI. Nevertheless, it has been shown that fasting increases the subjective value of high-calorie foods more than low-calorie foods (Goldstone et al., 2009). As fasting enhances the value and desire to eat food, it is hypothesized that hunger would have a greater effect on discounting of food that is more rewarding (i.e. greater discounting of HED, compared to LED, food).

This within-subjects study (Study 9), was an exploratory study, designed to assess how hunger, manipulated by nutritional state, influences both delay and probability discounting of both dietary and monetary rewards. On separate fasted and fed visits, participants completed delay and probability discounting tasks for money, HED food and LED food. First, in line with previous research (Bartholdy et al., 2016; Cameron et al., 2014; de Ridder et al., 2014; Sellitto & di Pellegrino, 2014; Symmonds et al., 2010), it is hypothesized that hunger will increase delay discounting and increase risk aversion on probability discounting tasks. Second, to explore how fasting impacts discounting of various commodities, differences between money and food discounting, and between HED and LED food are assessed. It is predicted that hunger would have a greater effect on discounting of food than money, and HED food than LED food. Third, to explore whether explicit hunger underpins changes in discounting the associations between the change in perceived hunger

and change in discounting across the two visits will be evaluated.

### 6.3 *Methods – Study 9*

#### 6.3.1 *Participants*

A sample of 22 healthy, non-obese adults were recruited by public advertisement. All volunteers provided written informed consent. This study was part of a wider functional MRI project investigating the effect of nutritional state on addictive behaviours. Participants were excluded if they were vegetarian, vegan, gluten or lactose intolerance, were obese (BMI  $<30.0\text{kg/m}^2$ ) or had recent weight change, were smokers, had any neurological, psychiatric, cardiovascular, endocrine, respiratory or gastrointestinal disorders, had a current or previous history of alcohol or drug abuse, were pregnant or breast feeding, had gastrointestinal surgery, had metal implants which would preclude safe MRI scanning, suffered from claustrophobia, or had an inability to use the right-handed button keypad. The study had been approved by the Imperial College London Research Ethics Committee (04/Q0406/18).

#### 6.3.2 *Study protocol*

In this randomised, within-subject study, participants were tested on two separate days, at least 5 days apart. Participants attended each visit within the follicular phase of their menstrual cycle (day 1-10). Participants were instructed to have their dinner at approximately 20.00 hours the evening before each visit, and not to eat or drink thereafter other than water. They were also instructed to avoid alcohol and vigorous exercise the day before each visit. Participants were informed only upon arrival whether they were attending for a 'fasted' or 'fed' visit.

During one visit, participants remained 'fasted' throughout the entire protocol (overnight mean  $\pm 14.9$ , SD  $\pm 1.3$  hours), whilst during the other visit, participants were in the 'fed' state and consumed a liquid breakfast at  $t = 0$  min. At  $t = +60$  min subjects had an MRI scan session lasting 1 hour, and at  $t = +150$  min performed the discounting tasks lasting 30 min in total. The discounting tasks were started at between 12:30-13:30. To avoid order

effect bias, a subset of the cohort ( $n=18$ ) was analysed in which half of the participants had their 'fasted' visit first, whilst the other half had their 'fed' visit first. BMI was calculated from height and weight taken on the participants' fasted visits.  $BMI = \text{weight}/\text{height}^2$ .

### 6.3.3 Discounting tasks

Both delay and probability discounting were measured using a computerised forced-choice task. In total, participants completed six separate discounting tasks; three separate tasks for money, HED food and LED food, for both delay and probability discounting. The task displayed amounts of hypothetical money (maximum £1,000) or photographs of hypothetical meals (maximum 1 whole serving), and on each trial participants pressed one of two buttons to indicate their preference for one of the two options. Images were presented side by side on a computer laptop using custom software in ePrime 2.0 Professional (Psychology Software Tools Inc., Sharpsburg, PA). For the food discounting tasks, one whole portion of the HED meal consisted of 1936.0 kcal of vegetarian pizza, 428.6 kcal of garlic bread and 330.0 kcal of chocolate. The LED consisted of 325.4 kcal of grilled chicken, 20.3 kcal salad, and 47.1 kcal of watermelon (Figure 6.1). For smaller serving sizes, photographs were taken with the appropriate amount of food removed from each plate, with text labels above indicating their relative size.



Figure 6.1. High- and low- energy density food photographs used as stimuli in both delay and probability food discounting tasks. One whole portion of the high-energy meal consisted



of 1936.0 kcal of pizza, 428.6.0 kcal of garlic bread and 330.0 kcal of chocolate. One whole portion of the low-energy meal consisted of 325.4 kcal of chicken, 20.3 kcal salad, and 47.1 kcal of watermelon.

### 6.3.3.1 *Delay discounting tasks*

The money delay discounting task required participants to select between small immediate rewards and larger delayed rewards (Du et al., 2002). In a series of trials participants indicated whether they preferred to receive a smaller amount of money now (£1,000, £900, £800, £700, £500, £250 or £100), or £1,000 at a delay (1, 2, 7, 30, 90, 180 or 360 days). In every trial, the delayed reward was always £1,000. Similarly, in the food discounting tasks participants were asked to choose between a hypothetical serving of the meal now (1 whole serving, 9/10<sup>th</sup>, 8/10<sup>th</sup>, 7/10<sup>th</sup>, 1/2, 1/4 or 1/10<sup>th</sup> of the entire portion), or the full serving at a delay (1, 2, 3, 4, 6, 9 or 12 hours). The delayed portion size was always constant at 1 whole portion. To deter participants from using the strategy of choosing the smaller immediate portion, with the intention of having more food immediately after the specified delay expires, participants were told to “choose as if the selected meal is the only food you will be able to eat until breakfast tomorrow”.

Initially, participants completed 7 trials of a novel practice task, with duration of holiday days as the reward commodity. Following this, in each experimental condition, participants completed seven blocks of seven trials. The trial order was randomised so that each reward (immediate or delayed) did not appear on the same side of the screen over three consecutive times. Crossing the 7 possible delay discounting and 7 reward magnitudes yielded 49 possible permutations for each reward condition (money, HED and LED food). In total, participants completed 6 separate discounting tasks in a randomised order between visits: delay then probability discounting, or probability then delay discounting, and within each discounting category, order was either HED food, money, LED food, or LED food, money, HED food, i.e. money was always the second block, with each block taking approximately 5 mins.

### 6.3.3.2 *Probability discounting tasks*

This task was identical to the delay discounting task; however, participants had to decide between either a large, fixed reward at a changing probability, and a smaller, certain reward, changing in amount. The certain smaller reward varied in amount (£1,000, £900, £800, £700, £500, £250 or £100), and the uncertain larger amount of money (fixed at £1,000), varied in the probability of it being received (90%, 80%, 70%, 50%, 25%, 10%, 5%). Additionally, participants completed two separate probability discounting tasks for HED or LED food. They indicated whether they preferred to receive a certain amount of the hypothetical meal now (1 whole serving, 9/10<sup>th</sup>, 8/10<sup>th</sup>, 7/10<sup>th</sup>, 1/2, 1/4 or 1/10<sup>th</sup> of the entire portion), or 1 whole serving now at a varying probability (90%, 80%, 70%, 50%, 25%, 10%, 5%). As with the delay discounting task, to deter participants from using the strategy of choosing the smaller certain portion with the intention of having more food afterwards, participants were told to “choose as if the selected meal is the only food you will be able to eat until breakfast tomorrow”. Similar to the delay discounting task, the trial order was randomised so that the certain or uncertain choice did not appear on the same side of the screen for three consecutive trials. The indifference point was defined at each probability as the smallest certain amount chosen before they switched to the fixed large reward at varying probability.

### 6.3.3.3 *Discounting task analyses*

For each participant, measures of delay and probability discounting were obtained from AUC values derived from task (Du et al., 2002). The indifference points were defined at each delay/probability as the smallest certain amount chosen before they switched to the fixed large reward. AUC values were calculated using the trapezoid method, reported in detail in Study 1 (Chapter 2). Smaller AUC values indicate steeper delay discounting, whereas smaller AUC values indicate greater risk aversion on the probability discounting tasks. Each participant had six separate AUC scores: three delay discounting (money, HED food, LED food) and three probability discounting (money, HED food, LED food). Participants

who did not reach an indifference point on the discounting tasks were excluded, as this reflects a technical error or otherwise a problem in understanding the requirements of the tasks.

#### *6.3.4 Questionnaires*

This experiment was part of a wider project investigating psychological traits. Participants completed a series of additional questionnaires at their first visit, however these are not reported in the current study.

#### *6.3.5 Appetite and mood ratings*

VAS ratings (0-10cm) were taken at specific time points ( $t = +60, +150, +180, +240$  min, relative to consumption of the meal on the fed visit or equivalent time point on the fasted visit) to measure hunger, pleasantness to eat, volume of food they thought they could eat, fullness, anxiety, stress and sleepiness (Bond & Lader, 1974; Goldstone et al., 2014). A composite appetite score was created from  $(\text{hunger} + \text{pleasantness to eat} + \text{volume of food they thought they could eat} - \text{fullness})/4$ . In the analysis the average VAS ratings and composite appetite score, at +150 min and +180 min (as these were respectively before and after the discounting tasks), were calculated for each score. Using these averages, the difference between each of the average VAS ratings and composite appetite score at the fasted and fed visits was calculated. In addition, at the end of the second visit, VAS scale ratings were taken to assess liking of the HED and LED meals. Participants were asked to rate how much they liked the taste of the food pictures used in the discounting tasks.

#### *6.3.6 Fixed meal*

In the 'fed' visit, participants consumed a liquid breakfast comprising a 500ml high-energy (1200 kcal) nutrition drink (Nutricia Fortisip Compact vanilla, Nutricia Ltd. Trowbridge, Wiltshire, UK) containing 46.5g of fat, 148.5g of carbohydrate and 48g of protein. Participants were offered ad libitum access to water in both sessions.

## 6.4 Data analysis

Initially, a manipulation check was conducted to ensure that fasting successfully increased hunger. The validity of the hunger manipulation was tested by comparing self-reported hunger at fasted and fed visits in a paired-samples t-test. To test the hypotheses that fasting increases delay discounting and decreases risk aversion, differences in discounting AUC scores at fasted and fed visits were calculated. Delay and probability discounting were calculated separately on fasted and fed visits. One-way, repeated-measures ANCOVAs with a single within-subject condition (fasted vs. fed) were used to assess discounting of money. To evaluate the difference in dietary discounting, two-way (HED vs. LED food) repeated-measure ANOCVAs, with a within-subject condition (fasted vs. fed) were conducted. Energy density was included as an effect to assess the differences in the effects of fasting on discounting between HED and LED food. These separate analyses (money and food) were conducted for both the delay probability discounting tasks. In all ANCOVAs, visit order was included as a covariate. In the ANCOVAs assessing discounting of food, liking was included as a covariate. It is acknowledged that the study was underpowered to assess individual differences. As such, correlations between discounting scores, BMI and demographic characteristics were not included in the analysis. Data are presented as mean  $\pm$  SD. All data were analysed using IBM SPSS statistics version 21 (IBM, New York, USA).

## 6.5 Results

### 6.5.1 Participant characteristics

The final data set resulted in 18 healthy non-obese adults (10 men, 8 women, age  $29.6 \pm 9.1$  years, BMI  $23.5 \pm 3.0$  kg/m<sup>2</sup>). There were 3 participants excluded for failing to reach an indifference point in the delay discounting task leaving  $N=15$ , and 1 participant excluded from the probability discounting task leaving  $N=17$ . See Table 6.2 for participant demographics and Table 6.3 for comparison of state VAS scale ratings between fasted and fed visits.

Table 6.2. Mean  $\pm$  standard deviation (*SD*) and range for participant characteristics ( $N = 18$ ).

	Mean $\pm$ SD	Range
Age (y)	29.6 $\pm$ 9.1	21.0 – 54.0
BMI (kg/m <sup>2</sup> )	23.5 $\pm$ 3.0	18.5 – 29.3
Liking – HED food (1-7)	6.2 $\pm$ 0.7	4.3 – 7.0
Liking – LED food (1-7)	6.1 $\pm$ 0.7	4.3 – 7.0

Table 6.3. Comparison of state variables between fasted and fed visits. 2-way paired t-test for fasted vs. fed conditions ( $N = 18$ ).

<i>State variables</i>	Fasted Mean $\pm$ SD	Fed Mean $\pm$ SD	<i>t</i> -statistic	<i>p</i> value
Average (+150mins and +180mins) VAS ratings (0-10):				
Hunger	7.4 $\pm$ 1.9	4.1 $\pm$ 2.7	7.6	0.002*
Appetite	5.8 $\pm$ 1.2	1.9 $\pm$ 1.7	-9.5	0.000**
Anxiety	1.1 $\pm$ 1.2	1.2 $\pm$ 1.4	0.3	0.78
Stress	2.1 $\pm$ 1.8	1.7 $\pm$ 1.3	0.7	0.47
Sleepiness	3.9 $\pm$ 2.5	4.4 $\pm$ 2.3	0.6	0.58

\* =  $p < 0.05$

\*\* =  $p < 0.001$

### 6.5.2 Manipulation check

Participants reported greater average (+150mins and +180mins) hunger on the fasted visit (See Table 6.3), compared with the fed visit,  $t(17) = 7.6, p = 0.002$ .

### 6.5.3 Delay discounting

#### 6.5.3.1 Difference between discounting AUC on fasted and fed visits

There was a main effect of fasted-fed condition on monetary delay discounting  $F(13) = 13.13, p = 0.003$ . Money delay discounting AUC was significantly higher when participants were fasted ( $0.54 \pm 0.27$ ), compared to fed ( $0.33 \pm 0.12$ ), indicating that participants were more future-oriented towards money when fasted (Figure 6.2). There was also a significant main effect of fasted-fed condition on dietary delay discounting,  $F(28) = 39.86, p = .00$ . Delay discounting AUC was lower, indicating greater impulsivity, when participants were fasted, compared to fed for both HED ( $0.27 \pm 0.22$  vs.  $0.63 \pm 0.27$ ) and LED ( $0.29 \pm 0.23$  vs.  $0.58 \pm 0.32$ ) food (Figure 6.2). There was no significant interaction between discounting and energy density,  $F(28) = 0.15, p = 0.70$ .

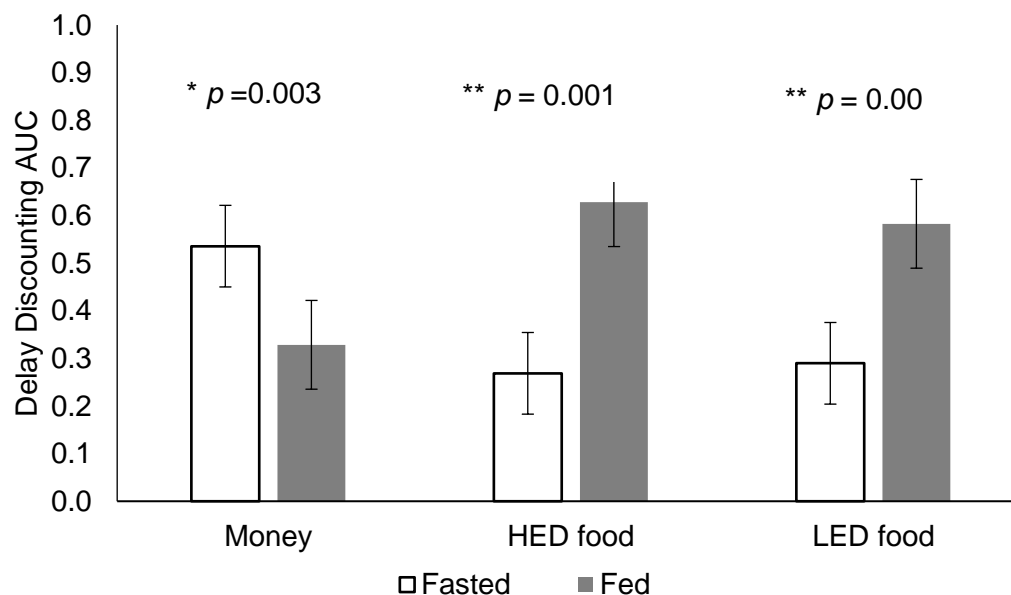


Figure 6.2. Delay discounting AUC for money, HED and LED food on fasted and fed visits. Error bars represent standard deviation.

## 6.5.4 Probability Discounting

### 6.5.4.1 Difference between probability discounting on fasted and fed visits

There was no significant difference between the monetary probability discounting when participants were fasted ( $0.26 \pm 0.12$ ) compared to fed ( $0.25 \pm 0.14$ ),  $F(15) = 0.12$ ,  $p = 0.73$ . Similarly, there was no significant main effect of fasted/fed condition on dietary probability discounting,  $F(30) = 0.14$ ,  $p = 0.72$ ., and no difference in probability discounting of HED and LED food,  $F(30) = 0.87$ ,  $p = 0.36$ . Discounting AUC were comparable when participants were fasted and fed for both HED ( $0.27 \pm 0.22$  vs.  $0.63 \pm 0.27$ ) and LED ( $0.29 \pm 0.23$  vs.  $0.58 \pm 0.32$ ) food (Figure 6.3).

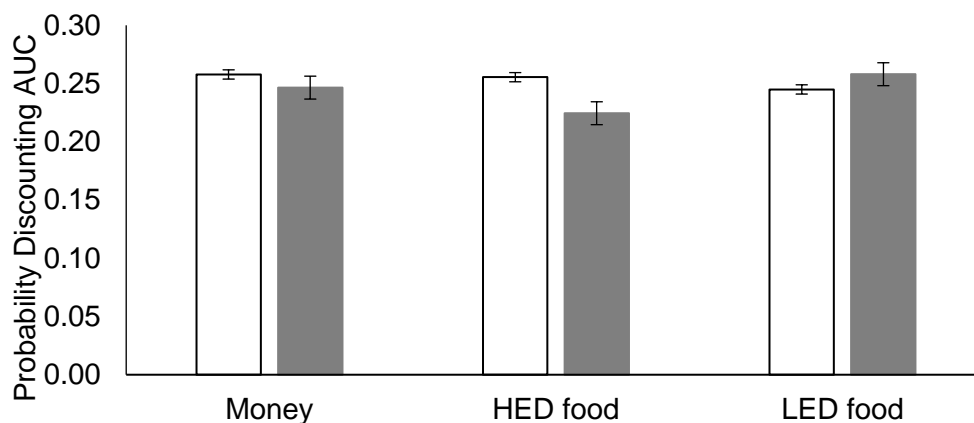


Figure 6.3. Probability discounting AUC for money, HED and LED food on fasted and fed visits. Error bars represent standard deviation.

## 6.6 Discussion

This study assessed the influence of fasting on delay and probability discounting. It was hypothesized that hunger, induced by manipulating nutritional state, would influence both delay and probability discounting. Specifically, it was predicted that fasting would increase delay discounting and decrease probability discounting. In addition, it was expected that these effects would have a greater effect when discounting food, compared to money. In

contrast to the hypothesis, probability discounting of food and money remained constant across nutritional states. In line with (de Ridder et al., 2014), where various measures of risk-aversion were implemented, our findings suggest that fasting does not affect risk taking behaviour. This challenges the intuitive hypothesis that hunger causes individuals to disregard possible consequences and make riskier decisions (Chang et al., 2016; de Ridder et al., 2014; Symmonds et al., 2010).

Contradictory findings may be explained by the variability in methodology. Typically, studies use the Iowa gambling task to measure risk aversion. Previous research has failed to find a relationship between performance on the IGT and probability discounting task (Olson, Hooper, Collins, & Luciana, 2007), implying that different risk-related cognitive processes mediate the two tasks. The IGT requires learning throughout the task to identify cards with overall positive net values. Hence, it is likely that the IGT taps into individual differences in learning speed, as well as risk-taking. Nutritional state, therefore, might not increase risk taking but instead may compromise learning speed, which impacts performance on the IGT. Further research is required to tease apart the distinct mechanisms by which fasting influences performance on varying measures of risk aversion.

Consistent with the hypothesis, delay discounting for both the HED and LED food increased when participants were fasted. One possibility is that the change in delay discounting of food may be attributed to a shift in reward value. Individuals are more likely to discount delayed or risky outcomes if the immediate reward has a higher perceived value (da Matta et al., 2012). Presumably, the value of the immediate food reward increased when fasting (Epstein et al., 2003), whereas the value of money remained constant. Indeed, fasting has shown to bias neural reward system activation to high-value food images (Goldstone et al., 2009). On the fasted visit, participants may have tended to choose the immediate portion over the delayed portion because it had a higher perceived value. Therefore, the change in discounting might not reflect a difference in temporal impulsivity, but a shift in value of the immediate food portion. However, if hunger did change the reward



value of food, then there should be less risk aversion to food on the fasted visit. Instead, probability discounting remained constant across nutritional states. Thus, the data suggests that, to some extent, hunger does indeed increase temporal impulsivity. It is proposed that the change in dietary delay discounting represents a combination of the both a change in reward value and an increase in temporal impulsivity.

Interestingly, there was no difference in the effect of fasting on delay discounting for HED and LED food. This suggests that hunger has a robust influence on dietary delay discounting, which increases temporal impulsivity towards all foods, regardless of energy density. These findings support the notion that dietary discounting is state dependent (Nederkorn, et al., 2009), suggesting that people prioritise their in-the-moment dietary needs when hungry. This may be an adaptive feature to increase motivation to satisfy immediate desires, over longer-term needs. For example, fasting has been shown to encourage food-seeking behaviour (Raynor & Epstein, 2003), and brain reward/hedonic responses to HED over LED foods (Goldstone et al., 2009). These behaviours may diminish the importance of future needs and override long-term goals. Indeed, when hungry, people forget about weight loss goals (Nordgren, van der Pligt, & van Harreveld, 2008), and report increased wanting of food (Ditto, Pizarro, Epstein, & MacDonald, 2006). It appears that hunger motivates individuals to devalue future rewards in favour of immediate satisfaction of their dietary needs.

The current findings may help to explain why dietary restriction encourages weight gain (Hays & Roberts, 2008); when hungry, the immediate desire to eat could override future health concerns. These findings could have important implications for our understanding of diets prescribed for weight loss. A diet or meal plan that intensifies hunger may encourage individuals to discount food more steeply. Discounting has been repeatedly associated with overeating, overweight and obesity (Barlow et al., 2016). Thus, avoiding extreme hunger might be important for reducing delay dietary discounting, especially for individuals struggling with their weight. This could have negative implications for weight loss attempts

that promote fasting, as exacerbated hunger could lead to more impulsive dietary behaviours. Moreover, nutritional state could have a different effect on dietary discounting in people with a high BMI. Future research is required to assess the long-term effects of hunger on delay impulsivity, and consequential weight gain, and the effects of hunger on discounting in an overweight and obese sample.

One potential mechanism by which fasting affects food-related delay discounting is the 'hunger' hormone, ghrelin. Ghrelin is known to increase food reward behaviour and increase impulsivity. Specifically, in rat models, ghrelin injections into the lateral ventricle increased monetary delay discounting (Anderberg et al., 2016). This suggests that ghrelin, secreted in response to an empty gut may increase impulsive behaviours, thus explaining why fasting changes dietary discounting. However, no research has examined the relationship between ghrelin and dietary discounting; future studies should assess the effects of manipulating ghrelin on food-specific delay discounting.

In contrast to food delay discounting, monetary delay discounting decreased when fasted. Similar improvements in monetary delay discounting have been observed (de Ridder et al., 2014), suggesting that hunger, counter-intuitively, reduces delay discounting of money. The improvement in monetary delay discounting may reflect reward transference – fasting may have increased the immediate value of food and reduced the immediate value of money, causing individuals to discount money less steeply. Furthermore, a different pattern of results was observed for the effects of fasting on monetary and dietary delay discounting. This supports growing body of evidence that delay discounting changes with the nature of the commodity (Amlung et al., 2016; Baker et al., 2003; Charlton & Fantino, 2008). This is an important distinction for future studies, reinforcing the notion that there is no single underlying delay-discounting process (Green & Myerson, 2013). It is particularly important that future studies consider this division when using monetary delay discounting-tasks to research eating behaviour and obesity. Interestingly, monetary and dietary probability

discounting were correlated, suggesting that people are equally risk averse to food and money.

A key methodological issue with this study is that participants were required to drink a high calorie drink in the fasted condition, but there was no control in the fed condition. This is likely to result in demand characteristics where participants are made aware of the difference between the conditions, and therefore can easily guess the study aim. To remedy this issue, future replications should give participants a similar, but very low-calorie, drink in the fasted condition. A further limitation with the dietary discounting tasks is that we did not account for variation in participants perceptions of the food. For instance, participants might have considered the whole portion to be too large, or not wanted to have consumed the entire serving. Thus, the task works under the assumption that more food is always more rewarding, which might not be the case. Additionally, the study may be limited by using computer-based judgements of food decisions. It remains to be determined whether the same relationships might be observed in a study of food intake related to discounting. This was beyond the scope of the present study but might be considered in future research. Finally, the generalizability of the findings remains unclear due to the small sample size and narrow BMI range.

## *6.7 Chapter summary*

In summary, fasting increased delay discounting of both LED and HED food, and decreased delay discounting of money, but had no effect on probability discounting. This suggests that nutritional state has domain specific effects on delay discounting, and no effect on risk aversion. This supports findings from Study 2 (Chapter 3) that temporal impulsivity is domain-specific, suggesting that delay discounting of food is significantly different from delay discounting of money. It is suggested that the effects of nutritional state on delay discounting of food are a combination of increased reward value of food and delay impulsivity. These findings merit consideration because they suggest reducing extreme hunger may be important for decreasing delay impulsive eating behaviours, and potentially consequential

weight gain. In line with previous findings, probability discounting did not change with nutritional state, challenging the notion that hunger influences risk-taking.

### *6.8 Acknowledgments*

We thank Imperial College Healthcare Charity and UK Medical Research Council for funding support, and Csaba Orban for assistance with data collection. SNA was an Imperial College Healthcare Charity Fellow.

## 7 Chapter 7.

### Summary and Conclusions

#### 7.1 Thesis overview

This chapter will summarise the primary findings from the nine studies presented in this thesis. This thesis applied different methods to research the relationships between meal timings, BMI and impulsivity. The studies presented combined two previously unrelated topics, meal planning and delay discounting, with the aim of improving our understanding of how the different ways in which individuals consider future events, specifically in relation to meal timings, may relate to eating behaviour and obesity. There was a specific focus on understanding how the length and certainty of an IMI influence portion size choices and relate to BMI and delay discounting. Broadly, five research questions were addressed:

1. Does the length and certainty of an expected IMI influence decisions about portion size? - Chapter 2 (Study 1), 3 (Study 2) and 4 (Studies 3, 4 and 5)
2. Is there a relationship between delay discounting of money, BMI and IMI sensitivity (the extent to which knowledge of future meal timings influences an individual's portion size selection)? - Chapter 2 (Study 1), 3 (Study 2) and 4 (Studies 3, 4 and 5)
3. What are the underlying factors that explain why individuals adapt their portion size based on the anticipated length of an IMI? - Chapter 4 (Studies 4 and 5)
4. Are individuals with a high BMI more likely to eat chaotically (at irregular times)? - Chapter 5 (Study 6, 7 and 8)
5. Does fasting influence discounting of food and money rewards? - Chapter 6 (Study 9)

The studies presented in each chapter were designed to answer these questions. This final chapter summarises the findings from these studies. The implications of the findings within the wider context of the obesity literature will be discussed, as well as limitations and suggestions for future research.

## *7.2 Main findings and implications*

### *7.2.1 Research question 1: Effects of the IMI on portion size decisions*

#### *7.2.1.1 Length of the IMI*

One of the central aims of this thesis has been to investigate whether information about the length of an IMI influences portion size decisions. The hypothesis that information about the length of an IMI would affect how much people choose to eat was explored in Studies 1 (Chapter 2), 2 (Chapter 3) and 3, 4 and 5 (Chapter 4). In Study 1 (Chapter 2), participants selected computerised portion sizes for lunch in response to information regarding the length of an IMI. Results showed that participants chose larger portions when the IMI was long, compared to short. To expand the generalisability of these results, the study presented in Study 2 (Chapter 3) tested these relationships in a sample with a wider BMI range and with broader range of IMIs. Indeed, the effect of the length of an IMI on portion size decisions was replicated in a sample of individuals with obese, overweight and normal BMI classifications. Similarly, to assess whether the effect is observed with real food intake, as well as computerised simulation, three separate experiments, presented in Chapter 4, were carried out to test whether individuals eat larger portions of real food in response to genuine IMIs of longer duration. Again, the results were consistent with Studies 1 (Chapter 2) and 2 (Chapter 3), suggesting that people do tend to eat larger portions in response to a longer IMI. These findings demonstrate that the influence of an anticipated IMI length on portion size selection is a robust effect, and one which is observed in individuals across a wide BMI range.

Although this may be considered an intuitive result, it nonetheless represents the first concrete demonstration of the way in which people use information about future meal timings to make portion size decisions. The conclusions from this thesis consequently represent a distinctive contribution to the literature by identifying a novel driver of portion size. It has been argued that the results have significant implications for eating behaviour research, particularly for experiments designed to measure portion size selection and food

intake. Until now, the influence of future meal timings on eating behaviour has been generally overlooked in studies exploring portion size and food intake. Typically, portion size studies require participants to select a portion for a stand-alone meal (e.g. Burger, Fisher, & Johnson, 2011; Wilkinson et al., 2012). It is standard practice for meals *prior* to the experiment to be controlled; for example, participants are often required to fast from the night before their experiment (e.g. Rolls, Morris, & Roe, 2002). However, it is unusual for studies to control for future meals. It is clear that people do not make portion size decisions in isolation, hence eating behaviour studies may produce inaccurate results where they fail to account for participants' expected IMI and food intake expectations *following* the experiment. Given that the length of an IMI significantly impacts portion size selection, individual differences in the timings of participants' post-experiment meals are likely to contribute to variations in portion size decisions. Therefore, to accurately isolate potential drivers of portion selection, it is important to control for the timings of post-experiment meals. Future studies should ensure that the length of the IMI is controlled for when assessing portion selection and food intake.

### *7.2.2 Research question 3: Exploring potential reasons why the length of an IMI influences portion size selection*

A key research question addressed in Studies 4 and 5 (Chapter 4) was to understand *why* meal timings influence portion size decisions, with the aim of isolating the underlying variables that change with the length of an IMI. One possible explanation was that people may be implicitly or explicitly concerned about potential hunger or fullness during the IMI, causing them to adjust their portion sizes. Results showed that participants expected to be hungrier at the next meal when the IMI was longer, compared to shorter, suggesting that participants ate larger portions to protect against future hunger. It was concluded that portion size is adapted to minimise the perceived adverse consequences of hunger during the IMI, rather than to meet in-the-moment energy needs. Future studies should look to evaluate whether attempts to mitigate participants' concerns about hunger could help to either

decrease portion sizes or prevent against overeating when experiencing hunger during the IMI. There was little evidence to support the hypothesis that subjective food reward value is influenced by the length of an IMI. Similarly, the findings did not show that the length of an IMI changes the expected satiety of food. Chapter 4 presented issues with methodology and power of the experiments in which these hypotheses were tested. These hypotheses merit further testing with more reliable measures and larger sample sizes.

### *7.2.3 Research question 1: Does an uncertain IMI lead to the selection of greater portion sizes?*

A key aim of the thesis was to explore the effects of an uncertain IMI on portion size decisions. It was hypothesised that uncertainty could motivate individuals to select larger portions to prevent against future hunger during the IMI. In Study 1 (Chapter 2), the impact of an uncertain IMI on portion size selection was investigated. In contrast to the hypothesis, there was little evidence that participants selected larger portions in response to an uncertain, compared to certain, IMI. Similar null findings were reported in a sample with a wider BMI range in Study 2 (Chapter 3), and with real food and IMIs in Study 3 (Chapter 4). As it stands, this thesis failed to provide evidence to support the hypothesis that pre-planning meal timings help to reduce portion size selection. Implications of this null finding are discussed below in the context of the findings related to chaotic eating that were presented in Chapter 5.

### *7.2.4 Research question 2: Is there a relationship between IMI sensitivity, BMI and delay discounting*

A further aim of the thesis was to explore individual differences in sensitivity to future meal timings. The term 'IMI sensitivity' reflects the extent to which an individual uses information about the IMI to make portion size decisions. Specifically, this thesis has examined sensitivity to information about both the length and certainty of IMIs. Relationships between individual differences, specifically BMI and delay discounting, with certain and uncertain IMI sensitivity were assessed in Study 1 (Chapter 2), and in a sample with a larger



BMI range in Study 2 (Chapter 3). This section will discuss the findings regarding individual differences in IMI sensitivity and the relationships to BMI and delay discounting.

#### *7.2.4.1 IMI sensitivity and BMI*

Findings from Study 1 (Chapter 2) provided evidence for a relationship between uncertain IMI insensitivity and high BMI. Individuals with a high BMI selected smaller portion sizes in response to an uncertain IMI, signifying that they are less sensitive to information about the uncertain IMI. No relationship was observed between high BMI and certain IMI sensitivity in Study 1 (Chapter 2), although it is argued that the effect was underpowered. Similarly, when replicated using real food and genuine meal timings in Chapter 4, there was no evidence for a relationship between BMI and certain IMI sensitivity. Nevertheless, these null findings can be attributed to the narrow BMI range of samples included in both of these studies. To explore whether this relationship extended to a sample with a wider range of BMIs, the study presented in Study 2 (Chapter 3) assessed whether both certain and uncertain IMI sensitivity differs between individuals who classify as obese, overweight or 'normal' weight. The results showed that individuals with obesity were less sensitive to information about the length of the certain IMIs. Similarly, individuals with a high BMI selected smaller portions when confronted with the uncertain condition. This reinforces findings from Study 1 (Chapter 2) and supports the hypothesis that individuals with a high BMI are less responsive to both the length and certainty of an IMI. These results are the first to show that IMI insensitivity is more prevalent in obese and overweight, relative to lean individuals. It was concluded that participants with a high BMI were less concerned about potential future fullness and hunger during the IMI. Future research is required to assess whether sensitivity to real IMIs is associated with high BMI in a sample with a wide BMI range.

#### *7.2.4.2 IMI sensitivity and delay discounting*

As well as establishing a relationship between BMI and IMI sensitivity, the experiments in Studies 1 (Chapter 2) and 2 (Chapter 3) tested the hypothesis that individuals

with low IMI sensitivity have a greater tendency to discount the future. In both Studies 1 (Chapter 2) and 2 (Chapter 3), the relationship between monetary delay discounting and portion sizes selected in response to an uncertain IMI was assessed. In both studies, individuals with high monetary discounting selected smaller portions when confronted with the uncertain condition. Furthermore, in Study 1 (Chapter 2), monetary discounting mediated a relationship between BMI and smaller portion selection in uncertainty. These results support the hypothesis that impulsive and overweight individuals are less concerned about the prospect of an uncertain IMI. Individuals who are not future-orientated may be less likely to engage in meal-planning strategies, which in turn could promote compensatory behaviours, such as increased between-meal snacking.

In both Study 1 (Chapter 2) and Study 2 (Chapter 3) there was no relationship between certain IMI sensitivity and monetary delay discounting, although power calculations revealed that the study was underpowered to show a significant effect. This suggests that the expression of delay discounting behaviour in relation to eating behaviour might depend on whether future meal timings are uncertain or uncertain. Indeed, individuals have been shown to discount a future reward more when the occurrence of a delayed event is less certain (Baumann & Odum, 2012; Green & Myerson, 2010; Patak & Reynolds, 2007). It was concluded from Study 1 (Chapter 2), that delay discounting may be more likely to be expressed when meal timings are uncertain. This suggests that a chaotic eating environment, in which meal timings are uncertain, might promote impulsive eating behaviours that lead to weight gain.

These are the first studies to link these two previously unrelated topics, meal planning and delay discounting. By demonstrating how future-orientated thinking relates to decision making in this context, the findings from Studies 1 (Chapter 2) and 2 (Chapter 3) provide a more nuanced understanding of how delay discounting manifests in eating behaviour. For instance, the role of discounting is often oversimplified in the literature on eating behaviour. It is widely assumed that individuals who discount the future are thought to lack inhibitory control and find it difficult to resist eating food. On the contrary, results from

Study 1 demonstrated that steep monetary delay discounting leads to the selection of *smaller* portions in response to an uncertain IMI. This illustrates that the effects of temporal discounting on eating behaviour and meal planning extend beyond the simplistic assumption that impulsive people always eat more because they lack self-control. The findings from this thesis suggest that the role of delay discounting is more complex than has heretofore been understood, and that the effects of delay discounting are expressed in short-term portion-size decisions from one meal to the next.

#### *7.2.5 Research question 4: Do individuals with a high BMI eat more chaotically (at irregular day-to-day timings)?*

As mentioned in the previous section, it was suggested in Study 1 that the expression of delay discounting on portion size decisions might depend on whether a meal time is planned or not. Specifically, it was concluded that delay discounting has a greater effect on portion size decisions when the length of the IMI is uncertain. Although uncertainty might increase the extent to which impulsivity manifests in portion size decisions, there was little evidence from Studies 1 (Chapter 2), 2 (Chapter 3), 3, 4 and 5 (Chapter 4) to support the hypothesis that an uncertain IMI would lead to the selection of larger-than-normal portion sizes. Given these contradictory findings, it is unclear as to whether uncertainty about future meal timings has negative implications for portion size decisions or BMI. Studies 6, 7 and 8 (Chapter 5) aimed to clarify whether eating patterns in which meal timings are uncertain have adverse consequences for food intake and body weight. This is particularly important given that there is currently little evidence to support dietary recommendations that encourage people to eat at regular meal timings as a weight loss strategy (Canada, 2017; Gov.au, 2012; NHS, 2017). The experiments presented in Chapter 5 assessed whether individuals with a high BMI eat more chaotically (at more variable meal timings). In Studies 6 and 7 (Chapter 5) chaotic eating was assessed using self-report questionnaires. In both studies, no relationship was found between chaotic eating and BMI. However, as discussed in Chapter 5, there were concerns with the self-report measure of chaotic eating, as it is

widely understood that people tend to underreport their eating habits on self-report questionnaires (Beechy et al., 2012; Berg et al., 2009; Johnson, 2002). To circumvent this issue, chaotic eating scores from 7-day weighted diet diaries using NDNS data were analysed in Study 8 (Chapter 5). Again, there was little evidence that BMI is associated with chaotic eating of meals or snacks. This is consistent with the conclusions drawn from Studies 1 (Chapter 2), 2 (Chapter 3), 3, 4 and 5 (Chapter 4) that an uncertain IMI does not significantly influence portion size selection. Together, the findings from this thesis fail to show any relationship between irregular meal timings with food intake or BMI.

One issue with the definition of chaotic eating is that it does not differentiate between irregular meal timings in the presence or absence of uncertainty. The observations from Study 1 (Chapter 2) suggest that delay discounting behaviours are more likely to manifest when meal times are uncertain. Hence, a subset of chaotic eaters who eat at uncertain meal timings might be more likely to eat impulsively, and therefore be prone to weight gain. Future studies should explore whether individuals who eat chaotically, and at uncertain meal times, have a higher BMI or greater daily food intake.

#### *7.2.6 Research question 5: Does fasting have an effect delay discounting of food and money rewards?*

In Study 9 (Chapter 6), the theory that discounting behaviours are state-dependent was explored. It was hypothesized that hunger, induced by varying nutritional state, would increase delay discounting and risk aversion to both HED and LED foods and money. Temporal discounting of both HED and LED food increased after fasting, whereas monetary temporal discounting decreased. Findings suggest that fasting increases temporal discounting of food, possibly because hunger increases the reward value of and/or impulsivity towards food, especially HED food, but not money. These findings support the theory that dietary discounting is state dependent (Nederkoorn et al., 2009). It was argued that people devalue future rewards in favour of immediate satisfaction of their dietary needs when hungry. As high delay discounting to both food and/or money has been associated

with obesity (for reviews, see Amlung et al., 2016; Amlung et al., 2017; Barlow et al., 2016; MacKillop et al., 2011), these findings suggest that reducing instances of extreme hunger may be important for lessening temporally impulsive eating, and consequentially reducing obesity. One method of avoiding extreme hunger could include paying greater attention to meal planning; more careful planning of future meals and food intake might be more likely to avoid leaving an individual in a state of extreme hunger. By contrast, in Study 9 (Chapter 6), risk aversion to HED and LED food and money was not found to be influenced by nutritional state. This contradicted previous findings that showed hunger improves risk aversion (de Ridder et al., 2014; Symmonds et al., 2010). It was argued that there needs to be greater consistency among the tasks used to measure risk aversion, and further research is required to establish whether fasting does indeed influence performance.

#### *7.2.7 Discounting of food vs. money*

An interesting finding that has emerged from the findings of Study 2 (Chapter 3) and Study 9 (Chapter 6), is that monetary and dietary delay discounting behaviours may be distinct. The results from Study 2 (Chapter 3) showed that monetary delay discounting and certain IMI sensitivity were unrelated predictors of BMI. Similarly, in Study 9 (Chapter 6), monetary delay discounting was not associated with dietary delay discounting of HED or LED food rewards, even when assessed using a similar task. This supports the notion that delay discounting is multifaceted (Green & Myerson, 2013), and is domain-specific (Baker et al., 2003; Charlton & Fantino, 2008). It appears that future-oriented decision-making strategies differ for food and money. For instance, evidence from Study 2 (Chapter 3) suggests that both may have independent effects on eating behaviour, and consequential weight gain. It is possible that using a money-based task, rather than a food-based task, could cause important effects and associations regarding short-term impulsive eating behaviours to be masked or misreported. Future studies should consider this distinction between monetary and dietary discounting, especially when using money-based tasks to assess delay discounting in eating behaviour and obesity.

One key difference between the food and money tasks implemented in both Study 2 (Chapter 3) and Study 9 (Chapter 6) is that the dietary discounting task required participants to discount future rewards at short-term intervals, whereas, the monetary task reflects a tendency to discount longer-term intervals. To establish whether delay discounting is a substance-specific trait, or whether the differences observed reflect variation in the interval time-frames, it would be useful to compare discounting of food and money at the same intervals in future studies.

### *7.3 Future directions for obesity interventions and research*

Given the current rapidly increasing obesity epidemic in the UK, and globally, developing weight loss strategies with a focus on reducing portion size and food intake is critically important. This thesis provides the first evidence that portion size decisions are influenced by the length of an IMI. Additionally, the research presented here highlights issues in the current understanding of how uncertain and irregular meal timings relate to BMI and delay discounting. The implications of the current findings in possible weight loss interventions will now be discussed.

Based on the finding that the length of an IMI influences portion selection, one approach could be to reduce the amount of time between two meals, which should lead to the selection of smaller portions. For example, people could eat dinner at an earlier time to reduce the IMI between lunch and dinner. Indeed, research has shown that eating late in the day is a risk factor for obesity, though evidence is inconclusive (Kinsey & Ormsbee, 2015). Based on the current findings, a longer IMI between lunch and dinner might promote the selection of larger portion sizes at lunchtime, which could increase food intake and lead to weight gain. However, decreasing an IMI could lead to compensation at different times of the day. For instance, having an earlier dinner might lead individuals to become hungrier between dinner and bedtime, and consequentially snack more, although there is little evidence that people compensate for a reduction in portion size (Rolls, Roe, & Meengs, 2006b). A weight loss intervention designed to reduce the length of the IMI should be tested

to examine whether it would decrease overall food intake, and body fat, or lead to compensatory behaviours.

An alternative strategy to reduce portion sizes, proposed in Chapter 4, could be to educate people about energy balancing with the aim of alleviating concerns about hunger. For example, knowledge of the saucepan-bathtub model of energy balancing (Rogers & Brunstrom, 2016) could help to reduce concerns about hunger when confronted with a long IMI, which would in turn, decrease portion size selection. However, evidence from Studies 1 (Chapter 2) and 2 (Chapter 3) showed that greater sensitivity to an IMI was associated with a low BMI, suggesting that adapting portion sizes based on predictions about hunger during the IMI could actually be a beneficial strategy. Adjusting portion sizes with expectations about future hunger might help to prevent against becoming prematurely hungry during the IMI. As shown from the results in Study 9 (Chapter 6), hunger might promote impulsive eating, which in turn could lead to overeating. Nevertheless, the negative effects of hunger might be further exacerbated if perceived to lead to adverse consequences (Rogers & Brunstrom, 2016). Future research is required to evaluate whether reducing concerns about hunger could help to either reduce portion size selection or prevent against overeating when experiencing hunger during the IMI.

A different intervention could be to promote future thinking in meal planning. For example, as outlined in Chapter 3, it has been reported that people with a high BMI are less likely to adhere to meal plans for weight loss (Aggarwal et al., 2010; Pijls et al., 2000; Thuan & Avignon, 2005). The finding that people with a high BMI are less sensitive to information about the length of an IMI might help to explain why overweight individuals are less responsive to meal plans, as reduced future sensitivity to meal timings might affect one's ability to maintain a structured eating routine. One possibility, therefore, is that future-thinking training could be implemented for individuals with a high BMI who are attempting meal-planning interventions. For example, studies have employed episodic future thinking tasks to reduce food intake and snacking in obese individuals (Daniel et al., 2013; Dassen et

al., 2016). The current findings might contribute to a novel intervention that promotes future-thinking about meal timings to help patients successfully adhere to structured meal patterns.

Nevertheless, the null findings from Studies 6, 7 and 8 (Chapter 5) raise doubts about whether eating in accordance to structure meal patterns has any effect on food intake or weight loss. This conclusion, combined with the lack of evidence that uncertain meal timings influence portion size selections presented in Studies 1 (Chapter 2), 2 (Chapter 3), 3, 4 and 5 (Chapter 4), has important implications for the current understanding of meal planning as a weight loss strategy. Regular and structured eating timings are recommended in healthy eating and weight loss guidelines (Canada, 2017; Gov.au, 2012; NHS, 2017). Although there is some evidence to suggest that eating outside of circadian rhythms, or at specific times (e.g. in the late evening), can influence weight regulation (Jakubowicz et al., 2013), health outcomes (Morgan et al., 2012), diet quality and adiposity (Eicher-Miller et al., 2016; Leech et al., 2017), this thesis has demonstrated that evidence for an association between irregular meal timings and BMI is weak. Further research should be conducted to interrogate the effectiveness of eating regularly on weight and food intake, to ensure that people's weight loss efforts are not being misdirected. As recommended in Chapter 4, a randomised controlled trial that compares the influence of eating at irregular vs. regular meal timings on food intake, diet quality and weight loss, should be conducted to evaluate the efficacy of the current guidance.

#### *7.4 Limitations*

Within each chapter, specific issues related to the experiments reported were discussed. Some general limitations will now be presented. First, many participants who took part in the experiments reported in this thesis were university students, hence the findings may not necessarily be generalisable to a non-student sample. This is particularly important when measuring eating patterns, as students might have a more chaotic or irregular eating pattern than the wider population. Furthermore, some studies (Study 9 in Chapter 6, Studies 3, 4 and 5 in Chapter 4, and Study 6 in Chapter 5) included samples with



a narrow BMI range. These findings may not be representative of the general population, so should be replicated using a non-student sample with a broader BMI range. However, this weakness is not applicable to all findings. The effect of the length and certainty of an IMI on portion size selection, and the association between IMI sensitivity with BMI and delay discounting, were replicated in a non-student sample with a wide BMI range in Study 2 (Chapter 3). Additionally, the null association between chaotic eating and BMI was established in two samples with a wide BMI range in Studies 7 and 8 (Chapter 5).

Second, the experiments in this thesis only investigated the short-term effects of information about the IMI on portion size judgements. There are several possible issues with assessing portion size selection within the context of a single meal, rather than across the day. For instance, people may compensate for the change in portion size by consuming more or less at later eating occasions, or on subsequent days. For example, individuals might eat less food when confronted with a short IMI but might go on to compensate for this reduction in energy intake by consuming larger portions or higher energy dense foods at the next eating occasion. However, evidence that people compensate for reductions or increases in portion sizes is mixed (Ebbeling et al., 2004; Kral & Rolls, 2004; Rolls et al., 2006a, 2006b, 2007; Shide, Caballero, Reidelberger, & Rolls, 1995). Nevertheless, compensation for changes in portion size has not been assessed in relation to the length of an IMI, thus this warrants further research. Additionally, there is likely to be more than one IMI within a day, whereas the studies presented in this thesis focused on the effects of a single IMI on portion size. It would be interesting to explore the cumulative effects of several IMIs on food intake across a day. Subsequent studies should investigate the influence of information about the IMIs across a day and observe whether portion size selections made in response to the length or certainty of an IMI lead to compensatory eating strategies.

Third, there were inconsistencies in which IMIs were assessed in each study. In Study 1 (Chapter 2) and Study 3 (Chapter 3), the IMI was between lunch and dinner, whereas in Studies 3, 4 and 5 (Chapter 4), the IMI was between breakfast and lunch.

Although conducting the 'real' food intake study at breakfast was more appropriate for University opening times, this is potentially limiting because the type of meal consumed might influence how the IMI effects portion size decisions. For example, there is evidence to suggest that the time-of-day of consumption differentially affects overall food intake (de Castro, 2004) and weight loss (Jakubowicz et al., 2013). By investigating the effects of inconsistent IMIs on portion selection, there is a lack of continuity and comparability between the findings, and variations in how information about the IMI effects portion size decisions at different meals may have been missed. Future research should compare the effects of information about the IMI on portion size selection of different meal times.

### *7.5 Conclusion*

This thesis has sought to assess several research questions regarding meal planning, eating patterns and impulsivity. For the first time, the findings reported in Chapter 2, 3 and 5 show that the length of an IMI influences portion size decisions, which could be an important variable to control in future portion size studies. Studies 1 and 2 (Chapter 2 and 3) introduced the novel theory that there are individual differences in the extent to which people may respond to, and make active use of, information about the IMI, in terms of the adjustments applied to portion size. It was shown that people with a high BMI are less sensitive to information about the length and certainty of an IMI. These findings have implications for our understanding of drivers of portion size, as well as potential weight loss strategies, such as future-thinking training to improve sensitivity to upcoming meal timings.

This thesis has combined two previously un-related fields, to show that delay discounting manifests in how people plan for the interval between two meals. Further novel findings regarding delay discounting in eating behaviour have also been revealed. Study 9 (Chapter 6) confirmed previous findings that temporal impulsivity towards food, but not money, increases with hunger. These findings could have important implications for weight loss strategies, as reducing instances of extreme hunger may be important for lessening temporally impulsive eating. Additionally, in both Studies 2 (Chapter 3) and 9 (Chapter 6),

monetary and dietary discounting were shown to be independent variables. This supports the notion that delay discounting behaviour differs with the commodity being discounted, and suggests that food-specific discounting tasks, rather than monetary tasks, should be used to evaluate the role of delay discounting in meal planning and eating behaviour. In sum, the studies have demonstrated the benefits of applying the findings from two different fields, delay discounting and meal patterning, to expand our understanding of how impulsivity and future thinking impact everyday dietary decisions and meal planning.

Finally, the thesis has revealed important limitations in the current research on eating patterns that promote obesity. There was little evidence in Study 1 (Chapter 2) to support the hypothesis that an uncertain IMI influences portion selection. Moreover, Studies 6, 7 and 8 (Chapter 5) failed to show an association between chaotic eating and BMI, thus calling into question the efficacy of recommendations that encourage individuals to eat at the same time each day as part of a weight loss strategy. Further research is needed to understand the role of eating patterns in obesity, particularly with the aim of elucidating how planning future meal timings influences food intake and weight gain.

## 8 References

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