Characteristics of obesity resistance and susceptibility

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Abstract

Background:
Obesity is well recognised as a disease process leading to multiple pathological consequences. Prevalence rates have increased to a point where more than one-third of people worldwide have a body mass index (BMI) ≥ 25 kg.m⁻² and for many nations overweight and obesity have become the norm. The obesogenic environment has been blamed for the marked increase in obesity rates in recent years. However, despite this dramatic increase a substantial sector of the population has remained lean, seemingly resistant to the obesogenic environment. Therefore, an alternative approach in determining cause, treatment, and prevention of obesity is to study those who appear resistant to the obesogenic environment. Information from this group should be valuable in developing potential strategies to aid those who continually struggle with their weight.

Objectives:
The overall aims of this thesis were:

1. To compare and contrast physiological, metabolic, behavioural and lifestyle characteristics of individuals who maintain a healthy body weight (BW) with relative ease i.e. obesity resistant individuals (ORI) with those who struggle to maintain a healthy BW i.e obesity susceptible individuals (OSI).
2. To compare the compensation capabilities of ORI and OSI in response to additional dietary energy intake.

Design:
To achieve the first overall aim a cross-sectional study called Born to be Lean (B2BL) was conducted with additional data on eating behaviour and sensitivity to fatty acid ingestion collected in two nested cross-sectional studies using ORI and OSI participants from the Ice Tea (IceT) study. The second overall aim was achieved by the IceT study intervention, a randomised, controlled, double-blind,
parallel study. For both studies, participants were classified as ORI or OSI based on their responses to pre-tested screening tool.

For the B2BL study, 34 ORI (17 females, 17 males) and 29 OSI (16 females, 13 males) with no history of chronic disease, thyroid disorder, metabolic disease, or eating disorders, and who were not currently smokers, pregnant, lactating or experiencing menopause, were recruited. Body composition was assessed using dual-energy x-ray absorptiometry (DXA). Fingerprick blood samples to measure ghrelin, total peptide YY (PYY), leptin, insulin and glucose along with appetite ratings measured using visual analogue scales (VAS) were collected at baseline and 15, 30, 60, 120 and 180 min following consumption of a standardised meal. Fasting, area under the curve, peak/nadir and time to peak/nadir were compared. Indirect calorimetry was used to measure resting metabolic rate (RMR) and comparison of measured RMR with three published RMR prediction equations was undertaken. Dietary intake was assessed using a four-day weighed diet record (4DDR). The International Physical Activity Questionnaire (IPAQ) and accelerometer data collected over 7 days was used to assess physical activity (PA) and sedentary behaviour. Dietary restraint, disinhibition and hunger were assessed using the Three Factor Eating Questionnaire (TFEQ).

For the IceT study intervention, 63 ORI and 55 OSI were recruited using the same classification procedures and exclusion criteria as the B2BL study, with the addition of phenylketonuria. Thirty ORI and 27 OSI were randomly assigned to consume a 500 ml sugar-sweetened (SS) beverage (~1000 kJ), while 33 ORI and 28 OSI were randomly assigned to consume a 500 ml artificially-sweetened (AS) beverage (~25 kJ) daily for 8 weeks. Body composition (DXA), dietary intake (4DDR), PA (pedometer) and blood lipids (venous blood sample) were assessed at baseline and at the end of the 8 week intervention. In addition, two nested cross-sectional studies were undertaken using participants from the IceT study cohort. In the first study restrained eating, emotional eating and external eating were assessed using the Dutch Eating Behaviour Questionnaire (DEBQ) and intuitive eating was assessed using the Intuitive Eating Scale (IES). The second study assessed oral sensitivity to oleic acid (1.4mM) using triplicate triangle tests and fat
ranking ability using samples of custard containing 0%, 2%, 6% and 10% canola oil.

**Outcomes:**
The results of the B2BL study showed significantly lower absolute RMR (P=0.036) and significantly higher RMR relative to BM (P=0.001) in ORI versus OSI. Female OSI had the lowest relative RMR (kJ·kg⁻¹·d⁻¹) compared to all other groups (P≤0.001). The three RMR prediction equations over-predicted RMR to some extent for male ORI and OSI but especially for female OSI. Levels of restrained eating and disinhibition were significantly lower in ORI versus OSI (P<0.001; P=0.005, respectively) while no significant differences were observed for hunger. Some differences were observed in the response to statements in the attitudes to exercise questionnaire with ORI more likely to agree with the statement ‘I am a sporty person’ (P=0.037) and OSI more likely to agree with the statement ‘I exercise to control my weight’ (P=0.002). No significant differences were observed in the majority of measurements relating to fasting and post-prandial hormone concentrations and appetite responses, dietary intake, physical activity and sedentary behaviour.

The results of the IceT study intervention showed a statistically significant increase in BW, waist circumference (WC) and percentage body fat (%BF) among those consuming the SS beverage compared to the AS beverage (P=0.016), but no interaction between ORS category and the intervention for any of these variables indicating that there was no evidence that the two ORS categories responded differently to the intervention. In the first nested cross-sectional study using participants from the IceT study cohort, significantly lower restrained eating and emotional eating was observed in ORI versus OSI (P<0.001; P=0.010, respectively) while scores for total intuitive eating and the three subscales of the IES were significantly higher in ORI versus OSI (all P≤0.003). Results of the second nested cross-sectional study showed the adjusted odds of being hypersensitive to oral fatty acid ingestion were 3.6 times higher in ORI versus OSI (P=0.034), but no significant differences were detected in the ability to rank the fat content of custard samples in the two ORS categories.
Conclusions:

The results from these studies suggest there are some measurable differences in the characteristics of ORI compared to OSI, especially with regard to RMR, eating behaviour and sensitivity to oral fatty acid ingestion. These findings have implications for both clinical practice and for the design of weight control interventions. The lower RMR relative to BW in OSI compared to ORI results in over-prediction of RMR by prediction equations, making it very difficult for these individuals to achieve the weight loss targets from planned energy restriction, especially for female OSI. Obesity resistant individuals exhibit more healthful eating behaviours and appear be more sensitive to oral fatty acid ingestion than OSI. Both of these characteristics are potentially modifiable and could therefore form part of programmes to assist individuals who struggle with weight control. The compensation capabilities of ORI and OSI were similar in response to additional dietary calories from a beverage, suggesting both groups are vulnerable to the insidious effects of SS beverages on weight gain.
Preface

This thesis is comprised of a literature review followed by two chapters covering the Born to be Lean (B2BL) Study and the Ice Tea (IceT) Study and then overall conclusions.

This research was supervised by Associate Professor Rachel Brown and Dr Paula Skidmore from the Department of Human Nutrition, University of Otago, and by Professor Rachael Taylor from the Department of Medicine, Dunedin School of Medicine, University of Otago and the Edgar National Centre for Diabetes and Obesity Research, University of Otago. Associate Professor Sheila Williams and Mr Andrew Gray from the Department of Preventive and Social Medicine, University of Otago provided expert statistical advice. Mrs Andrea Grant and Dr Kim Meredith-Jones conducted the DXA scans at the Dunedin Public Hospital DXA Scanning Unit. Mrs Sara Richardson and Miss Saskia van den Ende measured RMR in the School of Physical Education, Sport and Exercise Sciences, University of Otago. Dr Sarah Young (Department of Biochemistry, University of Otago) and Ms Michelle Harper (Department of Human Nutrition, University of Otago) provided assistance with blood analysis. Fat sensitivity tasting sessions were conducted by Dr Agnes Tey and Miss Davina Lee in the Department of Food Science, University of Otago. Dr Victoria Farmer provided advice and assistance with the analysis of the accelerometer data.

The candidate was responsible for the following:

Born to be Lean Study:

- Applications for funding and ethical approval
- Development of study protocols and questionnaires

The candidate was unable to be involved in the data collection as the start of this coincided with a period of parental leave. The day-to-day running of the study was carried out by Mrs Sara Richardson, a research assistant in the Department of Human Nutrition, University of Otago.
• Coding and entry of four day diet record data into a dietary assessment analysis programme
• All study data were entered twice, once by the candidate and once by other research staff involved in the project
• Ensuring quality of data entry
• Data cleaning, data analysis, and interpretation of results
• Disseminating findings and preparing this thesis

The Ice Tea Study:
• Applications for funding and ethical approval
• Development of study protocols and questionnaires and identification and selection of appropriate study beverages
• Registration of trial
• Participant recruitment and screening
• Communicating with study participants and providing instruction on study protocols and data collection
• Liasing with DXA technicians at Dunedin hospital, clinic nurses/phlebotomists in the Department of Human Nutrition and taste sensitivity experts in the Department of Food Science
• Sourcing and co-ordinating delivery and storage of study beverages
• Co-ordinating with research assistants who were responsible for blinding procedures of the study beverages
• Distributing study beverages and administering questionnaires to study participants
• Labelling, processing and storage of blood samples
• Laboratory analysis of plasma lipids and lipoproteins
• All study data were entered twice, once by the candidate and once by other research staff involved in the project
• Ensuring the quality of the data collection and data entry
• Data cleaning, data analysis, and interpretation of results
• Disseminating findings and preparing this thesis
A modified version of the hormone concentration, appetite responses and TFEQ analyses from the B2BL study have been published in Int J Endocrin 2014:512013; http://dx.doi.org/10.1155/2014/512013.

Findings from the B2BL study have been presented orally at the following conferences:

1. Nutrition Society of New Zealand in December 2016. An abstract will be published Nutrients.

Findings from the B2BL study have been presented as posters at the following conferences:


The B2BL study was supported by a University of Otago Research Grant.

A modified version of the sensitivity to oral fatty acid ingestion analysis has been published in Clin Nutr Diet 2015:1(1):7.

Findings from the IceT study have been presented as a poster at the following conference:

The IceT study was supported by an Otago Medical Research Foundation Laurenson Award, a Department of Human Nutrition PBRF Grant and BidVest Food Service Ltd.
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Sara Richardson, Dr Agnes Tey, Davina Lee, Saskia van den ende, Dr Lynnette Jones, Michelle Harper, Ashley Duncan, Sarah Young, Dr Kim Meredith-Jones, Andrea Grant, Prof Ailsa Goulding, Margaret Waldron, Lucy Peng, Sue Vorger, Dr Kavitha Menon, Tori Logan, Kieran Columb, Ivy Salih, Prof Dave Grattan, and Dr Alex Chisholm for assisting me with the projects, or providing professional advice or technical support.

All the staff and postgraduate students in the Department of Human Nutrition but especially Dr Katherine Black for making work outside my PhD fun and rewarding, administration geniuses - Anne Morrison and Madeline Sim, and Dr Tracy Perry for being my PhD convener.

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Finally, Nicholas Cooke for all your encouragement, love, understanding and efforts in helping to keep me on track. Thank you for always having my back and standing in my corner.

This thesis is dedicated to my father, Tony McLay, who sadly passed away at the very beginning of this journey, but has walked beside me all the way.
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<table>
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<tr>
<th>Abbreviation</th>
<th>Description</th>
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<tbody>
<tr>
<td>%BF</td>
<td>Percentage body fat</td>
</tr>
<tr>
<td>4DDR</td>
<td>Four-day weighed diet record</td>
</tr>
<tr>
<td>AEE</td>
<td>Activity-induced energy expenditure</td>
</tr>
<tr>
<td>AS</td>
<td>Artificially-sweetened</td>
</tr>
<tr>
<td>AUC</td>
<td>Area under the curve</td>
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<tr>
<td>B2BL</td>
<td>Born to be Lean</td>
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<tr>
<td>BMI</td>
<td>Body mass index</td>
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<tr>
<td>BMR</td>
<td>Basal metabolic rate</td>
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<tr>
<td>BW</td>
<td>Body weight</td>
</tr>
<tr>
<td>CHMS</td>
<td>Canadian Health Measures Survey</td>
</tr>
<tr>
<td>CHO</td>
<td>Carbohydrate</td>
</tr>
<tr>
<td>CI</td>
<td>Confidence interval</td>
</tr>
<tr>
<td>cpm</td>
<td>Counts per minute</td>
</tr>
<tr>
<td>CTI</td>
<td>Constitutionally thin individuals</td>
</tr>
<tr>
<td>CV</td>
<td>Coefficient of variation</td>
</tr>
<tr>
<td>DEBQ</td>
<td>Dutch Eating Behaviour Questionnaire</td>
</tr>
<tr>
<td>DXA</td>
<td>Dual-energy x-ray absorptiometry</td>
</tr>
<tr>
<td>EI:RMR</td>
<td>Ratio of energy intake to resting metabolic rate</td>
</tr>
<tr>
<td>FAO/UNU/WHO</td>
<td>Food and Agricultural Organisation/United Nations University/World Health Organisation</td>
</tr>
<tr>
<td>FFM</td>
<td>Fat-free mass</td>
</tr>
<tr>
<td>GLP-1</td>
<td>Glucagon-like peptide-1</td>
</tr>
<tr>
<td>HDL-C</td>
<td>High-density lipoprotein cholesterol</td>
</tr>
<tr>
<td>iAUC</td>
<td>Incremental area under the curve</td>
</tr>
<tr>
<td>IceT</td>
<td>Ice tea</td>
</tr>
<tr>
<td>IES</td>
<td>Intuitive Eating Scale</td>
</tr>
<tr>
<td>IES-2</td>
<td>Revised Intuitive Eating Scale</td>
</tr>
<tr>
<td>IPAQ</td>
<td>International Physical Activity Questionnaire</td>
</tr>
<tr>
<td>ISAK</td>
<td>International Society for the Advancement of Kinanthropometry</td>
</tr>
</tbody>
</table>
LBM  Lean body mass
LDL-C  Low-density lipoprotein cholesterol
LER  Low energy reporters
MET  Metabolic equivalent of task
MOSPA-Q  MONICA Optional Study of Physical Activity Questionnaire
MUFA  Monounsaturated fatty acid
MVPA  Moderate-intensity and vigorous-intensity physical activity
NCD  Noncommunicable diseases
NHANES  National Health and Nutrition Examination Survey
ORI  Obesity resistant individuals
ORS  Obesity resistance/susceptibility category
OSI  Obesity susceptible individuals
PA  Physical activity
PUFA  Polyunsaturated fatty acid
PYY  Peptide YY
RER  Respiratory exchange ratio
RMR  Resting metabolic rate
RMR_{est}  Estimated RMR
SD  Standard deviation
SE  Standard error
SFA  Saturated fatty acid
SRPAQ  Self-reported physical activity questionnaire
SS  Sugar-sweetened
TAG  Triacylglyceride
TC  Total cholesterol
TEI  Total energy intake
TFEQ  Three-factor eating questionnaire
TFI  Total fat intake
TSH  Thyroid stimulating hormone
USA  United States of America
VAS  Visual analogue scale
WC  Waist circumference
WHO  World Health Organisation
1 Introduction

The World Health Organisation (WHO) declared obesity to be an epidemic in 1998 [1]. Globally, obesity prevalence rates doubled between 1980 and 2008 [2] and it is now estimated that more than 2 billion individuals are overweight or obese [3]. In New Zealand the overall prevalence rate for overweight and obesity is almost two-thirds of the adult population [4]. This rapid rise in obesity in recent decades is of great concern due to the associated co-morbidities and subsequent strain on health care [5]. Obesity increases the risk of several non-communicable diseases (NCD) including diabetes, certain cancers, hypertension, coronary heart disease, osteoarthritis and gout [2, 3, 6]. In developed countries, the direct costs of obesity are estimated to be from 2 – 7% of total health care costs, representing one of the largest items of expenditure in health care budgets [7, 8].

Our so-called obesogenic environment has been blamed for the dramatic increase in obesity rates in recent years [9, 10] as genetics alone cannot account for such dramatic changes in a relatively short time-frame [11]. Features of the modern obesogenic environment include large portions of energy-dense, palatable, readily accessible and inexpensive food, increases in sedentary behaviour due to the development of labour-saving devices, and reduced physical activity (PA) at work, home, for transportation and recreation [9, 12, 13].

Some obesity experts have made dire predictions for future obesity prevalence rates. For instance, Wang et al [14] have predicted that by the year 2048, all American adults would become overweight or obese. However, evidence suggests that these predictions may be flawed. Data from cross-sectional and prospective studies on temporal changes in body mass index (BMI) indicate the population distribution of BMI is positively skewed and that over time the degree of skew has increased [15-19]. This means there is proportionally more shifting of the distribution curve at the upper end with the lower end of the distribution remaining relatively static [20]. This skewed distribution means that within a
population, more people are becoming overweight and obese, however, there still remains a substantial sector of the population who have remained lean, seemingly resistant to the obesogenic environment.

Theoretically, reducing energy intake and increasing energy expenditure should be the key to combating rising obesity levels and reducing the global burden of the disease. Unfortunately this simplistic strategy has largely been ineffective for the majority of individuals over the long term [21-24]. While most obesity researchers have examined the characteristics of overweight and obese individuals and populations in an attempt to determine the cause, treatment and prevention of obesity, a small number of research groups have used an alternative approach, investigating those who remain lean despite living in an obesogenic environment. It would seem highly likely that important differences must exist in the characteristics of those who maintain a healthy BW with relative ease (obesity resistant individuals) compared to those who struggle to maintain a healthy weight (obesity susceptible individuals). These characteristics can be categorised into five components: genetic, metabolic, physiological, behavioural and lifestyle (including dietary intake and PA).

To date, few human studies have been carried out to compare and contrast these characteristics in groups of people who differ vastly in their susceptibility to weight gain. Those that have been conducted have used varying definitions to describe obesity resistance (from lean to constitutionally thin) and obesity susceptibility (from reduced obese to obesity prone), making it difficult to directly compare results between studies. More recent investigations have defined obesity resistant individuals and obesity susceptible individuals based on a combination of self-identification, BMI and personal/family weight history.

Evidence from this limited pool of studies suggests potential differences may exist in hormone concentrations but investigations have often only included fasting levels or have been undertaken under controlled dietary conditions [25-30]. Very little data exists comparing the resting metabolic rate, dietary intake, physical activity and sedentary behaviour of individuals resistant and susceptible to obesity,
making it difficult to draw any strong conclusions regarding potential differences in these characteristics. In contrast, some work has been conducted comparing a small number of eating behaviour constructs, which indicates individuals resistant to obesity may have differing levels of restrained eating and disinhibition compared to individuals susceptible to obesity [31-34]. With such large gaps in the literature and many characteristics yet to be investigated there is a clear need for further work to elucidate if and what differences may exist between these two groups who differ markedly in their susceptibility to weight gain.

One of the potential consequences of living in an obesogenic environment is an increase in energy intake. An area of particular relevance with regard to obesity resistance/susceptibility is how an individual responds to additional calories. Evidence suggests that infants and young children exhibit accurate compensatory behaviours that facilitate energy balance regulation [35, 36]. On the other hand, a lack of consensus exists regarding the compensatory ability of adults [37]. In the only study to date investigating this ability in a group representing individuals resistant to obesity, Germain and colleagues [38] observed no change in the BW of constitutionally thin individuals (CTI) after 4 weeks of fat overfeeding. The ability of obesity resistant individuals to resist weight gain in an obesogenic environment may indicate that the compensatory capability present in childhood has been maintained into adulthood in this group. Conversely, a potential dysregulation may exist in obesity susceptible individuals that may result in a lack of precision in their ability to compensate for additional calories and this may help explain their continual struggle for healthy weight maintenance.

Rather than trying to ascertain what causes some people to become overweight, determining how some people manage to stay lean given the current environment we live in, may provide important information to allow us to develop novel strategies to benefit those who continually struggle to maintain a healthy BW. In addition, it may allow us to intervene in early childhood to promote sustainable obesity-preventing lifestyles or behaviours, which appears to be important given the unfortunate truth that obesity is increasing approximately equally in children and adults [39-42].
This thesis is comprised of two studies – the Born to be Lean (B2BL) cross-sectional study and the Ice Tea (IceT) intervention study. Two nested cross-sectional studies were also undertaken using participants from the IceT study cohort.

The primary aim of the B2BL cross-sectional study was:

- To compare and contrast physiological, metabolic, behavioural and lifestyle characteristics of individuals who maintain a healthy BW with relative ease i.e. obesity resistant individuals (ORI) with those who struggle to maintain a healthy BW i.e. obesity susceptible individuals (OSI).

The primary aim of the IceT study intervention was:

- To compare the compensation capabilities of ORI and OSI in response to additional dietary energy intake.

The primary aims of the IceT nested cross-sectional studies were:

- To compare and contrast restrained eating, emotional eating, external eating and intuitive eating behaviours of ORI and OSI.
- To compare and contrast the sensitivity to oral fatty acid ingestion of ORI and OSI.
2 Literature Review

2.1 Overview
This literature review introduces the prevalence, burden (section 2.2) and the aetiology (section 2.3) of obesity as a response to the obesogenic environment, before introducing the concept of ‘resistance’ to obesity section 2.4. The main body of the literature review then focuses on the potential characteristics that play a role in the resistance to obesity, namely physiological characteristics (section 2.5.1), metabolic characteristics (section 2.5.2), dietary intake (section 2.5.3), physical activity (PA) and sedentary behaviour (section 2.5.4), eating behaviour (section 2.5.5), and responses to energy manipulation (section 2.5.6).

Due to the nature of this topic, the breadth of potential material that could be included in this literature review is substantial. The few investigations that have compared the characteristics of obesity-resistant individuals (ORI) and obesity-susceptible individuals (OSI) have used a variety of definitions to describe obesity-resistance, including ‘obesity resistant’, ‘lean’, ‘lean-resistant’, ‘thin’ and ‘constitutional thinness’, and similarly for obesity-susceptibility - ‘obesity prone’, ‘reduced obese’ and ‘obese-susceptible’. As the focus of this thesis is to compare and contrast the characteristics of ORI and OSI, a study has only been included in Section 2.5 (Characteristics of Obesity Resistance) if the design involved a comparison between groups of lean/lean-resistant/thin/constitutionally thin/obesity resistant and obesity prone/reduced obese/obese-susceptible.

2.2 Obesity
The world is currently held firmly in the grip of an obesity pandemic. During the last half century the prevalence of obesity has risen markedly, starting in the Western world, but becoming more widespread to include developing countries [3, 43] until few areas remain untouched. Obesity is now a major contributor to ill health, disability and mortality in numerous regions of the world. Unfortunately, despite considerable efforts, most strategies aimed at reducing obesity rates have had limited success [23, 24, 44, 45].
2.2.1 Classification of Obesity

Overweight and obesity are terms that refer to an excess accumulation of body fat and reflect increased weight-for-height. Body mass index (BMI) (weight/height$^2$) has become the universally accepted population-level measure of the degree of overweight and obesity [46]. Body mass index (BMI) can be used to estimate the prevalence of obesity within a population and the adverse health risks associated with it. The most recent classifications of overweight (BMI ≥ 25) in adults by the World Health Organisation (WHO) [1] are presented in Table 2.1.

Table 2.1. Classification of overweight in adults according to body mass index (BMI) by the World Health Organisation (WHO)

<table>
<thead>
<tr>
<th>Classification</th>
<th>BMI (kg.m$^{-2}$)</th>
<th>Associated Health Risks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Underweight</td>
<td>&lt;18.5</td>
<td>Low (but increased risk of other clinical problems)</td>
</tr>
<tr>
<td>Normal range</td>
<td>18.50 – 24.9</td>
<td>Average</td>
</tr>
<tr>
<td>Overweight</td>
<td>≥25.0</td>
<td></td>
</tr>
<tr>
<td>Preobese</td>
<td>25.0 – 29.9</td>
<td>Increased</td>
</tr>
<tr>
<td>Obese class I</td>
<td>30.0 – 34.9</td>
<td>Moderately increased</td>
</tr>
<tr>
<td>Obese class II</td>
<td>35.0 – 39.9</td>
<td>Severely increased</td>
</tr>
<tr>
<td>Obese class III</td>
<td>≥40.0</td>
<td>Very severely increased</td>
</tr>
</tbody>
</table>

2.2.2 Prevalence of Overweight and Obesity

The global prevalence of obesity doubled between 1980 and 2008 (WHO, 2012) and 36.9% of men and 38% of women worldwide have a BMI ≥ 25 kg.m$^2$ [3]. New Zealand, like other industrialised nations, has seen overweight and obesity become the norm. Almost one-third (30%) of New Zealand adults are obese and a further third (35%) are overweight [4]. The situation is even more alarming in Māori and Pacific groups, with obesity affecting nearly half of Māori (45% males, 48% females) and almost two-thirds of Pacific adults (61% males, 68% females) [4]. Presently, there are an estimated 1.2 million obese New Zealanders [47].

Although data from developed countries suggest the increase in overweight and obesity rates has slowed down [3, 43, 48, 49], rates are still rising in the
developing world [3, 43, 50]. According to Ng and colleagues [3], the number of individuals globally who were overweight or obese in 2013 was 2.1 billion, illustrating that the prevalence of obesity has never been greater.

### 2.2.3 Global Burden of Obesity

A recent discussion paper from the McKinsey Global Institute (2014) declared obesity as one of the top three global social burdens generated by human beings. According to estimates made by the Institute, obesity has roughly the same economic impact (US$2.0 trillion) as smoking (US$2.1 trillion) or armed conflict (US$2.1 trillion) [7].

The adverse effects of obesity on health are well known, considerable and causal. Overweight and obesity increase the risk of a number of major non-communicable diseases (NCD), including diabetes, hypertension, coronary heart disease and certain types of cancer [2, 3, 6, 51]. Non-communicable diseases (NCD) were responsible for 68% (38 million) of the world’s 56 million deaths in 2012 and represent a major health challenge in terms of both human suffering and the damage they cause to the socioeconomic structure of countries [6]. Other co-morbid conditions that can occur as a result of obesity include sleep apnoea, osteoarthritis, infertility, lower extremity venous stasis disease, gastroesophageal reflux and urinary stress incontinence [51].

Studies conducted in developed economies to assess the obesity toll have estimated the health care costs to be between 2% and 7% of total health care spending [7, 8, 52]. These are direct costs related to ambulatory care, hospitalisation, drugs, radiological or laboratory tests, and long term care of the overweight or obese individual [8]. Substantial indirect costs are also incurred due to decreased years of disability-free life, increased mortality before retirement, early retirement, disability pensions, work absenteeism and reduced productivity [7, 8]. It has been suggested that the economic cost of lost productivity is several times greater than the direct medical costs [53, 54]. It also appears likely there is an additional economic burden associated with severe obesity (BMI ≥ 40 kg.m^{-2})
[55], which unfortunately also seems to be the fastest growing category of obesity [56].

The health care costs attributable to overweight and obesity in New Zealand in 2006 were estimated to be NZ$623.9 million or 4.4% of the total health care expenditure [52], plus an additional estimated cost of NZ$98 – 225 million due to lost productivity. Obesity rates have risen from 26.5% in 2006/07 [57] to an estimated 30% at present [4]. Therefore the undue stress placed on the New Zealand health care system by the burden of obesity, and its associated co-morbidities, is undoubtedly even greater at the present time.

2.3 The Obesogenic Environment

The underlying reasons for the global obesity epidemic are complex and it is likely there are multiple origins. Genetics undoubtedly plays a role, but genetics alone cannot account for such rapid development in such a short timeframe at the population level [11]. Many experts agree that the environment is fueling this epidemic as the increased prevalence of obesity over the last few decades has occurred in parallel with many environmental changes [9, 10, 13, 58]. Further, it has been suggested that much of the individual variability in bodyweight might be attributable to gene-environment interactions [9, 59, 60]. George Bray described this concept simply and clearly when he stated “the genetic background loads the gun, but the environment pulls the trigger” [61].

The ‘obesogenic environment’ was first described by Swinburn and colleagues [62] as “the sum of influences that the surroundings, opportunities, or conditions of life have on promoting obesity in individuals or populations”. These researchers contended that the physical, economic, legislative, social, and cultural environments of the majority of industrialised countries encourage positive energy balance in their populations by making it easy for them to overeat and under-exercise. The relative contribution of factors influencing food intake and PA are not necessarily clear, however evidence from several studies suggest that changes in the global food system, and in particular increases in food supply, are the
dominant drivers of population weight gain [63-66]. Since the 1960-70s in many high-income countries there has been an increase in the supply of readily accessible, convenient, inexpensive, overly palatable, energy-dense food served in large portions, and marketed by increasingly persuasive and pervasive methods [9, 10, 12, 58, 67].

In addition, the modern environment discourages PA at work, at home, for transportation and for recreation, compounding the energy imbalance. Advancements in technology have made it possible to be productive while being largely sedentary, as PA has been essentially engineered out of our daily lives [13, 58, 68]. Labour-saving devices such as cars, elevators, remote controls, household appliances and computerisation and automation of many previously physically active occupations have reduced daily energy expenditure. This, coupled with a decrease in leisure-time PA as people spend more time sitting passively in front of screens (television, computers, video games etc) [13, 67, 68] has also contributed to population weight gain and the emergence of the obesity epidemic.

2.4 Obesity Resistance

Future obesity prevalence rates have been predicted to reach extraordinary levels by some obesity experts [14, 56, 69-72]. For example, Kelly et al [69] proposed if recent secular trends continued unabated 20% of the world's adult population would be obese and 38% overweight by 2030. Wang and colleagues [14] predicted that by 2048 all American adults would become overweight or obese, with black women attaining that status by 2034. However, information from cross-sectional and prospective studies on temporal changes in BMI conducted in various parts of the world, including the USA [15], England [16], Australia [17], the Netherlands [18], and New Zealand [19] indicate these predictions may be flawed. These data suggest that the population distribution of BMI does not follow a normal (Gaussian) distribution, but rather is positively skewed and that over time the degree of skew has increased. This means that there is proportionally more shifting at the upper end of the distribution curve with the lower end of the
distribution remaining relatively static. The actual changing patterns of BMI are reflected in Figures 2.1B and 2.1C, and not 2.1A.

**Figure 2.1.** Possible changes over time in the population distribution of body mass index (BMI). (A) = upward shift (dashed line) of the entire population distribution; (B) and (C) = positively skewed distribution, with proportionally more shifting of the distribution curve at the upper than the lower end. Reproduced with permission: [20] (Appendix A)

So although more people are becoming overweight and obese, even among the most obese nations on earth, there exists a substantial number of individuals who have remained lean seemingly resistant to the obesogenic environment. If 65% of New Zealand adults are overweight or obese at present, then it follows that 35% are not.

In an attempt to determine the cause, treatment and prevention of obesity, the majority of obesity research has concentrated on the characteristics of overweight individuals and populations. There is, however, a small but developing area within the obesity research field where the focus has shifted to those who appear to be resistant to the obesogenic environment. Although a full description is outside the
scope of this literature review, there is a growing body of work using rodent models, to compare differences between obesity-resistant and obesity-susceptible animals. Among high-fat feeding rats, some rats become obese, whereas others do not [73]. This model, to some extent, mimics that of people living in a modern obesogenic society. According to a recent review by Ding and colleagues [74], studies using rodent models comparing obesity-resistant and obesity-susceptible animals have demonstrated differences in gastrointestinal fat absorption, appetite regulation, hormone levels, PA, fat storage, and fat consumption.

Studies that have directly investigated the characteristics of obesity-resistant compared to obesity-susceptible humans are limited. In addition, as previously described, within this modest body of literature a number of different terms have been used to define and describe both obesity-resistant and obesity-susceptible humans [75]. With regard to ORI, some researchers have used the term ‘lean’ [29, 30, 76] or ‘lean-resistant’ [28], however, this does infer some knowledge of body composition; others have used the term ‘thinness’ [31, 32]; and some have used the term ‘constitutional thinness’ which refers to individuals who are thin through no conscious action on their part [25, 38, 77]. Reduced-obese individuals i.e. individuals who have recently successfully lost weight on some sort of weight-reduction programme, were initially selected to represent OSI [29, 30, 32, 78]. These individuals have a high probability of weight gain in the next 6 -12 months, but also may have altered biology compared to that of a pre-obese individual, potentially limiting this approach [75].

More recent studies (published from 2012 onwards) have defined and selected ORI and OSI based on a combination of self-identification, BMI and personal/family weight history [26, 33, 34, 79-82]. For example, in the study conducted by Schmidt and colleagues [82], obesity resistant participants who responded to advertisements for ‘naturally thin people’, had a BMI of 16.9 – 25.5 kg.m⁻², had no first degree relatives with a BMI > 30 kg.m⁻² and defined themselves as constitutionally thin based on their perception of difficulty gaining weight despite not expending any effort to maintain their current weight. These individuals reported no history of ever being overweight and self-reported a sense that their
weight regulation was ‘different’ from other people. In contrast, obesity prone
individuals had a BMI of 19.6 – 30.6 kg.m$^{-2}$, had at least one first degree relative
with a BMI > 30 kg.m$^{-2}$, reported having to put effort into not gaining weight,
reported previous attempts to lose weight, but were not actively attempting to lose
weight and were weight stable for at least 3 months before being studied.

To date, the focus of research comparing ORI with OSI has included investigations
into the impact of energy imbalance on spontaneous PA [82]; hunger, satiety, and
energy intake [31]; eating behaviour [34]; energy expenditure and nutrient
oxidation [80]; and hormonal and metabolic responses [26]. Other researchers
have examined appetite control and food motivation in response to a high fat diet
[76], postprandial metabolic responses to a high lipid load [28], and appetite and
hormone responses to a standardised meal [38]. A number have used functional
magnetic resonance imaging to investigate the neuronal responses to visual food
cues and sweet taste under conditions of underfeeding, overfeeding and in a
eucaloric state [32, 33, 79, 81].

The key studies that have contributed to the field of obesity resistance and hence
form a significant part of this literature review are listed in Table 2.2. The reader
is referred to this table for details of the aim, group definitions, participant
characteristics, and relevant outcomes of these studies.

2.5 Characteristics of Obesity Resistance
As previously stated, the body of literature dealing with obesity resistance is
limited and as such few defining characteristics specific to this group have been
fully identified. Investigating the possibility of variation in the genetic make-up or
neurofunction of ORI compared to OSI are two potentially informative and
expansive research avenues, however, both genetic profiling and brain imaging are
beyond the scope of this thesis. The following sections have been limited to
reviewing the literature on those characteristics we identified for inclusion in our
research. The selection of these characteristics was based firstly on there being an
Table 2.2. Summary of relevant studies within the obesity resistance literature

<table>
<thead>
<tr>
<th>Author (y) Study Aim</th>
<th>Classification of Groups</th>
<th>Participant Characteristics</th>
<th>Variables of Interest</th>
<th>Outcomes of Interest</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cornier et al [33]</td>
<td>OR (Obesity Resistant):</td>
<td>OR: N=24 (12 F, 12 M) mean BMI = 20.6 kg.m⁻²</td>
<td>Eating Behaviour Baseline TFEQ (mean ± SD)</td>
<td>Restrained Eating: OR &lt; OP (5.0 ± 3.0 vs 9.3 ± 4.5; p&lt;0.001)</td>
</tr>
<tr>
<td></td>
<td>• BMI 17-25 kg.m⁻²</td>
<td>OP: N=25 (12 F, 13 M) mean BMI = 26.5 kg.m⁻²</td>
<td></td>
<td>Disinhibition: OR &lt; OP (3.2 ± 2.3 vs 8.0 ± 3.2; p&lt;0.001)</td>
</tr>
<tr>
<td></td>
<td>• responded to advertisements for ‘naturally thin people’</td>
<td></td>
<td></td>
<td>Hunger: OR &lt; OP (4.6 ± 2.5 vs 6.4 ± 3.0; p&lt;0.005)</td>
</tr>
<tr>
<td></td>
<td>• self-defined as ‘constitutionally thin’ based on their perception of difficulty gaining weight, expending little effort to maintain weight and sense of body weight regulation that was different to others</td>
<td></td>
<td></td>
<td>No difference in F vs M</td>
</tr>
<tr>
<td></td>
<td>• no obese first degree relatives</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>• never overweight</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>• weight stable despite few to no attempts to lose weight</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>• no high levels of physical activity</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>OP (Obesity Prone)</td>
<td>All healthy adults</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>• BMI 20-30 kg.m⁻²</td>
<td>Age 25-40 y</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>• responded to advertisements for ‘people who struggle with their weight’</td>
<td>No medical or psychiatric disease (including depression and eating disorders)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Author(s)</td>
<td>Study Aim</td>
<td>Classification of Groups</td>
<td>Participant Characteristics</td>
<td>Variables of Interest</td>
</tr>
<tr>
<td>----------</td>
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</tr>
</tbody>
</table>
| Germain et al [25] | To evaluate appetite regulatory hormones in constitutionally thin in an inverse paradigm of diet-induced weight loss. | CT (Constitutionally Thin):  
- BMI 13-17.5 kg.m⁻²  
- stable body weight throughout post-pubertal period  
- no amenorrhea  
- no eating disorders  
- no markers of under-nutrition including normal IGF-1, oestadiol, free triiodothyronine, cortisol, non-blunted leptin  
- no hepatic disorders  
- no over-exercising behaviours according to MOSPA-Q  
- outpatient consultation regarding body weight gain  
Controls  
- BMI 18.5-25 kg.m⁻²  
- age-matched with CT  | CT  
N=8  
mean BMI = 17.1 kg.m⁻²  
Controls  
N=8  
mean BMI = 22.1 kg.m⁻²  
All healthy females  
Age 18-36 y  
Non-smokers  
No medication use  | Hormone Levels:  
Baseline fasting leptin (mean ± SEM)  
RMR:  
Baseline REE (mean ± SEM) assessed using indirect calorimetry  | Leptin: CT < Controls  
(8.3 ± 1.4 vs 12.6 ± 0.9 ug.L⁻¹; P=0.04)  
Absolute REE: CT < Controls  
(4748 ± 209 vs 5669 ± 134 kJ.d⁻¹; P<0.05)  
Relative REE: NS differences  
(CT = 144 ± 6; Controls = 142 ± 3 kJ.kg⁻¹.d⁻¹)  |  
Dietary Intake:  
Baseline 5 d ‘dietary daily-self reporting record’ (mean ± SEM)  | Energy: NS differences  
(CT = 8198 ± 670; Controls = 7658 ± 444 kJ.d⁻¹)  
Protein: NS differences  
(CT = 19 ± 0.7; Controls = 19 ± 1.2 %TEI)  
CHO: NS differences  
(CT = 59 ± 1.5; Controls = 62 ± 1.4 %TEI)  
Fat: NS differences  
(CT = 84 ± 7.7; Controls = 69 ± 4.7 g.d⁻¹)  
(CT = 22 ± 1.5; Controls = 19 ± 1.9 %TEI)  
SFA: NS differences  
(CT = 44 ± 2.9; Controls = 47 ± 1.1 %TFI)  
MUFA: NS differences  
(CT = 43 ± 2.5; Controls = 40 ± 0.8 %TFI)  
PUFA: NS differences  
(CT = 13 ± 1.9; Controls = 13 ± 0.6 %TFI)  
Energy Gap (TEE – TEI): NS differences  
(CT = -1180 ± 523, Controls = 477 ± 447)  |  
Physical Activity:  
Baseline 5 d accelerometer (Actiheart) measured AEE (mean ± SEM)  | AEE: NS differences  
(CT = 6782 ± 720; Controls = 6644 ± 945 kJ.d⁻¹)  |  
Eating Behaviour:  
Baseline DEBQ (mean ± SEM)  | Restrained Eating: CT < Controls  
(12.9 ± 18 vs 26.3 ± 2.7; P=0.010) |
<table>
<thead>
<tr>
<th>Author (y) Study Aim</th>
<th>Classification of Groups</th>
<th>Participant Characteristics</th>
<th>Variables of Interest</th>
<th>Outcomes of Interest</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thomas et al [26]</td>
<td>OR (Obesity Resistant)</td>
<td>OR</td>
<td>Hormone Levels</td>
<td>Leptin: OR &lt; OP</td>
</tr>
<tr>
<td>To investigate hormonal and metabolic responses to short-term overfeeding and underfeeding in individuals recruited as obese-resistant (OR) or obese prone (OP)</td>
<td>Same group classification as Cornier, Shott et al (2015)</td>
<td>N=29 (14 F, 15 M) mean BMI = 20.9 kg.m(^{-2})</td>
<td>leptin, insulin, ghrelin, PYY, GLP-1, and glucose</td>
<td>(598 ± 71 vs 1881 ± 72 ng.ml(^{-1}); p&lt;0.001)</td>
</tr>
<tr>
<td></td>
<td>OP (Obesity Prone)</td>
<td>OP</td>
<td></td>
<td>Insulin: OR &lt; OP</td>
</tr>
<tr>
<td></td>
<td>Same group classification as Cornier, Shott et al (2015)</td>
<td>N=29 (15 F, 14 M) mean BMI = 26.1 kg.m(^{-2})</td>
<td>AUC (mean ± SD) assessed following 4 d of a eucaloric diet and a eucaloric breakfast meal</td>
<td>(6908 ± 452 vs 9147 ± 436 ng.ml(^{-1}); p&lt;0.05)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>All healthy adults</td>
<td></td>
<td>Ghrelin: OR &gt; OP</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Age 25-35 y</td>
<td></td>
<td>(147256 ± 2286 vs 124586 ± 2207 ng.ml(^{-1}); p&lt;0.05)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>No medical or psychiatric disease (including depression and eating disorders)</td>
<td></td>
<td>PYY: NS differences</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Matched for age (± 2 y), sex and ethnicity/race</td>
<td></td>
<td>(OR = 22784 ± 644; OP = 21307 ± 658 pg.ml(^{-1}))</td>
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<td>GLP-1: NS differences</td>
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<td></td>
<td></td>
<td>(OR = 2002 ± 203; OP = 1713 ± 211 pmol.L(^{-1}))</td>
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<td>Glucose: NS differences</td>
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<td></td>
<td></td>
<td>(OR = 15603 ± 265; OP = 16332 ± 256 mg.dL(^{-1}))</td>
</tr>
<tr>
<td>Cornier et al [81]</td>
<td>OR (Obesity Resistant)</td>
<td>OR</td>
<td>Appetite Responses:</td>
<td>Hunger: “How hungry are you right now?” (not at all hungry – extremely hungry)</td>
</tr>
<tr>
<td>To examine the differences in neuronal response to visual food cues in adults recruited as either obesity-resistant (OR) or obesity-prone (OP).</td>
<td>Same group classification as Cornier, Shott et al (2015)</td>
<td>N=25 (11 F, 14 M) mean BMI = 20.9 kg.m(^{-2})</td>
<td>Hunger VAS at 0, 30, 90, 120, 150, 180 min, assessed following 4 d of a eucaloric diet and eucaloric liquid breakfast meal</td>
<td>Fasting Hunger: NS differences</td>
</tr>
<tr>
<td></td>
<td>OP (Obesity Prone)</td>
<td>OP</td>
<td></td>
<td>(OR = 66 ± 20 vs OP = 70 ± 23 mm)</td>
</tr>
<tr>
<td></td>
<td>Same group classification as Cornier, Shott et al (2015)</td>
<td>N=28 (14 F, 14 M) mean BMI = 26.2 kg.m(^{-2})</td>
<td>Fasting and AUC (mean ± SD)</td>
<td>AUC Hunger: NS differences</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Age 25-40 y</td>
<td></td>
<td>(OR = 7325 ± 3259 vs OP = 8698 ± 3331 mm.180min(^{-1}))</td>
</tr>
<tr>
<td></td>
<td></td>
<td>All free of medical and psychiatric diseases, including depression and eating disorders</td>
<td></td>
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</tr>
<tr>
<td>Author (y) Study Aim</td>
<td>Classification of Groups</td>
<td>Participant Characteristics</td>
<td>Variables of Interest</td>
<td>Outcomes of Interest</td>
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</tr>
<tr>
<td>Thomas et al [34]</td>
<td>OR (Obesity Resistant)</td>
<td>OR N=29 (14 F, 15 M) mean BMI = 20.9 kg.m-²</td>
<td>Appetite Responses:</td>
<td>Hunger: &quot;How hungry are you right now?&quot; (not at all hungry - extremely hungry)</td>
</tr>
<tr>
<td></td>
<td>Same group classification as Cornier, Shott et al (2015)</td>
<td>OP N=29 (15 F, 14 M) mean BMI = 26.1 kg.m-²</td>
<td>Hunger, prospective food consumption and satiety VAS at 0, 30, 60, 90, 120, 150, 180 AUC (mean ± SEM) assessed following 4 d of a eucaloric diet and eucaloric breakfast meal</td>
<td></td>
</tr>
<tr>
<td></td>
<td>OP (Obesity Prone)</td>
<td>All healthy adults Age 25-35 y Matched for age (± 2 y), sex and ethnicity/race</td>
<td>Eating Behaviour</td>
<td>Physical Activity:</td>
</tr>
<tr>
<td></td>
<td>Same group classification as Cornier, Shott et al (2015)</td>
<td></td>
<td>Baseline TFEQ (mean ± SD)</td>
<td>Base line 7d pedometer (Digi-Walker) measured steps per day (mean ± SD)</td>
</tr>
<tr>
<td>Schmidt et al [82]</td>
<td>OR (obesity resistant)</td>
<td>OR N=32 (16F, 16 M) mean BMI = 20.6 kg.m-²</td>
<td>Restrained Eating:</td>
<td>Steps per day:</td>
</tr>
<tr>
<td></td>
<td>Same group classification as Cornier, Shott et al (2015)</td>
<td>OP N=23 (15 F, 8 M) mean BMI = 23.8 kg.m-²</td>
<td>OR &lt; OP (4.6 ± 3.0 vs 9.4 ± 4.4; p&lt;0.001)</td>
<td>NS differences (OR = 9082 ± 501; OP = 9984 ± 608 steps.d⁻¹; p=0.26)</td>
</tr>
<tr>
<td></td>
<td>• BMI 16.9 – 25.5 kg.m⁻²</td>
<td>All healthy adults Age 25-35 y No medications, medical illness, eating disorders or psychological dysfunction</td>
<td>Disinhibition: OR &lt; OP (3.1 ± 2.2 vs 7.7 ± 3.5; p&lt;0.001)</td>
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<tr>
<td></td>
<td>OP (obesity prone)</td>
<td>• BMI 19.6 – 30.6 kg.m⁻²</td>
<td>Hunger: OR &lt; OP (4.5 ± 2.4 vs 6.3 ± 2.9; p&lt;0.05)</td>
<td></td>
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<tr>
<td></td>
<td>Same group classification as Cornier, Shott et al (2015)</td>
<td>• matched to OR for age and RMR</td>
<td></td>
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</tr>
<tr>
<td></td>
<td>• BMI 16.9 – 25.5 kg.m⁻²</td>
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</tr>
<tr>
<td></td>
<td>• matched to OR for age and RMR</td>
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<td>Author (y) Study Aim</td>
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</tr>
</tbody>
</table>
| Cornier et al [32] | Thin | Thin  
• BMI 19-23 kg.m⁻²  
• no family history of obesity  
• weight stable by self-report > 10 y  
RO (Reduced Obese)  
• 8-10% body weight loss in a supervised weight loss programme  
• maintained new reduced weight for 8 wk prior to study entry | Eating Behaviour:  
Baseline TFEQ (mean ± SD)  
Restrained Eating: Thin < RO  
(4.3 ± 3.7 vs 8.1 ± 4.2; P<0.05)  
Disinhibition: Thin < RO  
(4.5 ± 3.1 vs 6.8 ± 3.5; P<0.05)  
Hunger: NS differences  
(Thin = 5.1 ± 3.8; RO = 4.9 ± 2.0) | |
| Galusca et al [27] | Thin | CT (Constitutionally Thin)  
• BMI 12-16.5 kg.m⁻²  
• stable body weight throughout the post-pubertal period  
• presence of physiological menstruation without oestrogen-progestin therapy  
• medical consultation sought due to desire for weight gain  
• no coeliac disease, infectious diseases, cancer or other consumptive diseases  
Controls  
• normal weight  
• medical students  
*An additional group of anorexia nervosa patients were also included in this study. | Hormone Levels:  
fasting leptin (mean ± SEM)  
Leptin: CT < Controls  
(6.0 ± 0.8 vs 11.2 ± 1.9 µg.L⁻¹; P<0.005) | |
<table>
<thead>
<tr>
<th>Author (y)</th>
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</tr>
</thead>
<tbody>
<tr>
<td>Bossu et al [77]</td>
<td>To evaluate the energy metabolism, including simultaneous assessment of food intake and total energy expenditure in very-low-weight CT subjects, compared with those of normal BMI controls and with those of anorexia nervosa patients displaying similar very low body weight.</td>
<td>CT (Constitutionally Thin) • BMI 14.5-16.5 kg.m⁻² • stable body weight throughout the post-pubertal period • presence of physiological menstruation without oestroprogestative treatment • medical consultation sought due to desire to gain weight Controls • normal weight</td>
<td>CT  N=7 mean BMI = 16.1 kg.m⁻² AN N=6 mean BMI = 15.8 kg.m⁻² Controls N=7 mean BMI = 21.2 kg.m⁻² All young age-matched (18-26 y) Caucasian females</td>
<td>Hormone Levels: fasting leptin (mean ± SD)</td>
<td>Leptin: NS differences (CT = 8.3 ± 3.4; Controls = 9.0 ± 3.1 ng.ml⁻¹)</td>
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<td>Absolute RMR: CT &lt; Controls (4839 ± 473 vs 5576 ± 209 kJ.d⁻¹; P&lt;0.05)</td>
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<td>RMR: Baseline RMR (mean ± SD) assessed using indirect calorimetry</td>
<td></td>
<td>Relative RMR: CT &gt; Controls (148.6 ± 5.4 vs 131.8 ± 10.4 kJ.kgFFM⁻¹.d⁻¹; P&lt;0.05)</td>
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<td>Dietary Intake: Estimated 4 day diet record (mean ± SD)</td>
<td></td>
<td>Energy: NS differences (CT = 7565 ± 908; Controls = 7961 ± 1452 kJ.d⁻¹)</td>
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<td>Physical Activity: Energy expenditure due to physical activity assessed using MOSPA-Q and AEE assessed by doubly-labelled water (mean ± SD)</td>
<td></td>
<td>Protein: NS differences (CT = 13.0 ± 2.2; Controls = 14.5 ± 19 %TEI)</td>
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<td>CHO: NS differences (CT = 50.7 ± 7.5; Controls = 46.4 ± 5.1 %TEI)</td>
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<td>Lipids: NS differences (CT = 36.2 ± 6.7; Controls = 39.0 ± 5.6 %TEI)</td>
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<td>Physical Activity EE (MOSPA-Q): NS differences (CT = 1430 ± 284; Controls 2051 ± 1314 kJ.d⁻¹)</td>
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<td></td>
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<td></td>
<td>AEE (DLW): NS differences (CT 3542 ± 464; Controls 3207 ±410 kJ.d⁻¹)</td>
</tr>
<tr>
<td>Germain et al [38]</td>
<td>To test the hypothesis that concentrations of appetite-regulating hormones in constitutionally thin (CT) subjects would be comparable with those of normal-weight subjects, but an additional group of anorexia nervosa patients were also included in this study.</td>
<td>CT (Constitutionally Thin) Same group classification as Bossu et al (2007)</td>
<td>CT  N=10 mean BMI = 15.7 kg.m⁻² Controls N=7 mean BMI = 20.4 kg.m⁻² All young age-matched (18-27 y) Caucasian females No medication use</td>
<td>Hormone Levels: Fasting and 24 h profiles of PYY, GLP-1, ghrelin, leptin (mean ± SEM)</td>
<td>Fasting: PYY: CT &gt; Controls (31.1 ± 1.3 vs 26.8 ± 1.2 pmol.L⁻¹; P&lt;0.001) GLP-1: CT &lt; Controls (73.2 ± 48 vs 82.6 ± 5.5 pmol.L⁻¹; P&lt;0.001) Ghrelin: CT &lt; Controls (324 ± 24 vs 499 ± 23 pmol.L⁻¹; P&lt;0.001) Leptin: NS differences CT vs Controls (CT = 7.7 ± 0.7; Controls = 9.3 ± 0.5 ug.L⁻¹)</td>
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<td></td>
<td>24 Hour profiles (data presented in figures): PYY: CT &gt; Controls (P&lt;0.05)</td>
</tr>
</tbody>
</table>

*An additional group of anorexia nervosa patients were also included in this study.
<table>
<thead>
<tr>
<th>Author (y) Study Aim</th>
<th>Classification of Groups</th>
<th>Participant Characteristics</th>
<th>Variables of Interest</th>
<th>Outcomes of Interest</th>
</tr>
</thead>
</table>
| different from those of patients with anorexic (AN). | Resistant (Lean-Resistant)  
• BMI < 25 kg.m⁻²  
Susceptible (Obese-Susceptible)  
• BMI > 30 kg.m⁻² | Resistant  
N=9  
Susceptible  
N=9  
All healthy young males  
Similar high fat intake (>40%TEI) and comparable physical activity  
Age-matched (21-35 y)  
Stable body weight in for 3 mo prior to study entry | Dietary Intake:  
Estimated 4 day diet record (mean ± SD) | GLP-1: NS difference  
Ghrelin: CT < Controls (P<0.05)  
Leptin: NS differences  
Energy: NS differences  
(CT = 7821 ± 850; Controls = 8150 ± 958 kJ.d⁻¹) |
| Marrades et al [28]  
To determine the role of macronutrient oxidation ability in the postprandial response to a high lipid load in the mechanisms conferring resistance or susceptibility to obesity. | | | Hormone Levels:  
Fasting leptin, insulin and glucose (mean ± SEM) | Leptin: Resistant < Susceptible  
(8.3 ± 2.6 vs 33.3 ± 4.6 ng.ml⁻¹; P<0.001)  
Insulin: Resistant < Susceptible  
(3.6 ± 0.1 vs 10.5 ± 3.1 μUI.ml⁻¹; P=0.001)  
Glucose: NS differences  
(Resistant = 90.3 ± 3.9; Susceptible = 92.7 ± 2.3 mg.dL⁻¹)  
Absolute RMR: Resistant < Susceptible  
(5.03 ± 0.12 vs 6.18 ± 0.14 kJ.min⁻¹; P<0.0001)  
Relative RMR (adjusted for FFM and FM): NS differences  
(Resistant = 5.59 ± 0.97; Susceptible = 5.61 ± 0.13 kJ.min⁻¹)  
Energy: NS difference  
(Resistant = 2267 ± 259, Susceptible = 2799 ± 171 kcal.d⁻¹)  
CHO: NS difference  
(Resistant = 256 ± 25, Susceptible = 272 ± 12 g.d⁻¹)  
(Resistant = 37 ± 6.9, Susceptible = 39 ± 1.6 %TEI)  
Fibre: NS difference  
(Resistant = 19 ± 3, Susceptible = 15 ± 2 g.d⁻¹)  
Protein: NS difference  
(Resistant = 108 ± 7, Susceptible = 127 ± 10 g.d⁻¹)  
(Resistant = 16 ± 1.1, Susceptible = 18 ± 1 %TEI)  
Total Fat: NS difference  
(Resistant = 137 ± 17, Susceptible = 132 ± 12 g.d⁻¹)  
(Resistant = 45 ± 2.2, Susceptible = 43 ± 1.8 %TEI) |
<table>
<thead>
<tr>
<th>Author (y) Study Aim</th>
<th>Classification of Groups</th>
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<th>Variables of Interest</th>
<th>Outcomes of Interest</th>
</tr>
</thead>
<tbody>
<tr>
<td>Therrien et al [29]</td>
<td>Lean</td>
<td></td>
<td>SFA: NS difference</td>
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</tr>
<tr>
<td></td>
<td>• BMI &lt; 27 kg.m⁻²</td>
<td></td>
<td>(Resistant = 39 ± 6,</td>
<td></td>
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<tr>
<td></td>
<td>• WC &lt; 100 cm (M); &lt; 90 cm (F)</td>
<td></td>
<td>Susceptible = 33 ± 3 g.d⁻¹)</td>
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<td></td>
<td>Obese</td>
<td></td>
<td>MUFA NS difference</td>
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</tr>
<tr>
<td></td>
<td>• BMI 30-35 kg.m⁻²</td>
<td></td>
<td>(Resistant = 84 ± 11,</td>
<td></td>
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<tr>
<td></td>
<td>• WC &gt; 100 cm (M); &lt; 100 cm (F)</td>
<td></td>
<td>Susceptible = 80 ± 9 g.d⁻¹)</td>
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<tr>
<td>RO (Reduced Obese)</td>
<td>• BMI &gt; 30 kg.m⁻² and WC &gt; 100 cm (M); &lt; 100 cm (F) before minimal weight loss of 5 kg</td>
<td></td>
<td>PUFA: NS difference</td>
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<td></td>
<td>• weight loss from dietary or physical activity changes, not medication or extreme diets</td>
<td></td>
<td>(Resistant = 15 ± 2, Susceptible = 19 ± 4 g.d⁻¹)</td>
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<td></td>
<td>• still losing weight or just weight stabilised</td>
<td></td>
<td>Hormone Levels:</td>
<td></td>
</tr>
<tr>
<td></td>
<td>N=28 (12 F, 16 M)</td>
<td>Lean F and RO F &lt; obese F (P&lt;0.01)</td>
<td>Fasting leptin, and glucose</td>
<td></td>
</tr>
<tr>
<td></td>
<td>mean BMI: F = 22.6 ± 0.7; M = 24.4 ± 0.7 kg.m⁻²</td>
<td>Lean &lt; obese M and RO M (P&lt;0.001)</td>
<td>(mean ± SE)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Obese</td>
<td>Lean M &lt; obese M and RO M (P&lt;0.001)</td>
<td></td>
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<td></td>
<td>N=29 (10 F, 19 M)</td>
<td>Lean F and RO F &lt; obese F (P&lt;0.01)</td>
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<tr>
<td></td>
<td>mean BMI: F = 33.4 ± 1.2; M = 32.3 ± 0.5 kg.m⁻²</td>
<td>Hormone Levels:</td>
<td>Glucose: NS differences in M</td>
<td></td>
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<tr>
<td></td>
<td>RO</td>
<td>Lean F &lt; obese F and RO F</td>
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<td>N=25 (9 F, 16 M)</td>
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<td></td>
<td>mean BMI: F = 30.7 ± 1.6; M = 29.9 ± 0.7 kg.m⁻²</td>
<td>Glucose: (data presented in a figure)</td>
<td>(4.9 ± 0.1 vs 5.3 ± 0.1 (both) ug.dL⁻¹; P&lt;0.01)</td>
<td></td>
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<tr>
<td></td>
<td>All healthy adults</td>
<td>Leptin:</td>
<td></td>
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<tr>
<td></td>
<td>Age 23-50 y</td>
<td>Lean M &lt; obese M and RO M (P&lt;0.001)</td>
<td></td>
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</tr>
<tr>
<td></td>
<td>No depression or psychiatric disorders</td>
<td>Lean F and RO F &lt; obese F (P&lt;0.01)</td>
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<tr>
<td></td>
<td>Non-smoking</td>
<td>Hormone Levels:</td>
<td>Glucose:</td>
<td></td>
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<tr>
<td></td>
<td>No medication use</td>
<td>Baseline fasting glucose, insulin, and leptin (mean ± SD)</td>
<td>Lean &lt; RO; F &lt; M</td>
<td></td>
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<tr>
<td></td>
<td>Premenopausal females, normal menstruation, no oral contraceptive use</td>
<td></td>
<td>(Lean F = 77.7 ± 4.6, Lean M = 85.7 ± 3.3 vs RO F = 86.1 ± 4.0, RO M = 90.5 ± 6.7 mg.dL⁻¹; P&lt;0.05)</td>
<td></td>
</tr>
<tr>
<td>Cornier et al [30]</td>
<td>Lean</td>
<td>Insulin:</td>
<td>Hormone Levels:</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• BMI 19-23 kg.m⁻²</td>
<td>Lean &lt; RO</td>
<td>Baseline fasting glucose, insulin, and leptin (mean ± SD)</td>
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</tr>
<tr>
<td></td>
<td>RO (Reduced Obese)</td>
<td>F &lt; M</td>
<td></td>
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<tr>
<td></td>
<td>• Initial BMI 30-35 kg.m⁻²</td>
<td>Lean F = 4.3 ± 1.6, lean M = 4.2 ± 1.1 vs RO F = 6.1 ± 0.8, RO M = 4.8 ± 1.1 µUI.ml⁻¹; P&lt;0.05)</td>
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<tr>
<td></td>
<td>• ≥ 10% weight loss in supervised</td>
<td>Lean &lt; RO</td>
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### Participants Characteristics

<table>
<thead>
<tr>
<th>Author</th>
<th>Study Aim</th>
<th>Outcomes of Interest</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Baseline glucose kinetics in lean and reduced-obese (RO) individuals.</td>
<td>Only RO F = M = 1.2 ± 0.6 vs RO F = 1.4 ± 0.8; M = 1.4 ± 0.9</td>
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<td></td>
<td>Lean: F = 1.5 ± 0.6 vs M = 1.2 ± 0.8; Reduced: F = 0.4 ± 0.6 vs M = 0.4; Reduced: F = 1.2 ± 0.8 vs M = 1.2 ± 0.8; RO: F = 1.4 ± 0.8 vs M = 1.4 ± 0.9</td>
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<tr>
<td></td>
<td>Adequate weight loss maintained in all participants</td>
<td>Adequate weight loss maintained in all participants</td>
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<tr>
<td></td>
<td>All healthy</td>
<td>All healthy</td>
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<td>Age 25-45y</td>
<td>Age 25-45y</td>
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</tbody>
</table>

### Variables of Interest

- **Glucose Kinetics in Lean and Reduced-obese (RO) Individuals:**
  - Baseline glucose kinetics in lean and reduced-obese (RO) individuals.
  - Only RO F = M = 1.2 ± 0.6 vs RO F = 1.4 ± 0.8; M = 1.4 ± 0.9
  - Lean: F = 1.5 ± 0.6 vs M = 1.2 ± 0.8; Reduced: F = 0.4 ± 0.6 vs M = 0.4; Reduced: F = 1.2 ± 0.8 vs M = 1.2 ± 0.8; RO: F = 1.4 ± 0.8 vs M = 1.4 ± 0.9
  - Adequate weight loss maintained in all participants.
  - All healthy.
  - Age 25-45y.

### Classification of Groups

- **Glucose Kinetics in Lean and Reduced-obese (RO) Individuals:**
  - Weight loss programme maintained to within 2%.
  - Weight loss maintained throughout study.

### Converted Text

- **Author:** Cornier et al.
- **Study Aim:** To test the hypothesis that thin individuals, who appear to be resistant to weight gain in an obesogenic environment, would better sense excessive caloric intake with appropriate changes in measures of hunger, satiety, and ad libitum intake than reduced-obese individuals who are at high risk for weight gain.

### Participant Characteristics

- **Thin:**
  - BMI < 23 kg.m⁻²
  - Weight loss programme prior to study entry
  - Age 25-45y

- **Reduced-obese (RO):**
  - Initial BMI 30-35 kg.m⁻²
  - 8-10% weight loss in supervised weight loss programme
  - Maintained weight loss for ≥4 wk prior to study entry
  - Age 25-45y

### Outcomes of Interest

- **Appetite Responses:**
  - Pre-meal Hunger: NS differences
  - Post-meal Satiety: NS differences
  - Prospective Consumption: NS differences

- **RMR:**
  - Baseline RMR (mean ± SD) assessed using indirect calorimetry

- **Eating Behaviour:**
  - Baseline TFEQ (mean ± SD)

- **Absolute RMR:**
  - NS differences; F < M (P < 0.05)

- **Restrained Eating:**
  - NS differences

- **Disinhibition:**
  - Thin F = 2.3 ± 1.0, Thin M = 3.4 ± 2.3 vs RO F = 8.8 ± 3.0, RO M = 7.8 ± 3.9; P < 0.05

- **Hunger:**
  - NS differences; F < M (P < 0.05)

- **AEE:** activity-induced energy expenditure,
- **AUC:** area under the curve,
- **BMI:** body mass index,
- **CHO:** carbohydrate,
- **CT:** constitutionally thin,
- **DEBQ:** Dutch Eating Behaviour Questionnaire,
- **DLW:** doubly-labelled water,
- **EE:** energy expenditure,
- **F:** female,
- **FFM:** fat-free mass,
- **GLP-1:** glucagon-like peptide-1,
- **IGF-1:** insulin-like growth factor,
- **M:** male,
- **MOSPA-Q:** MONICA Optional Study of Physical Activity Questionnaire,
- **MUFA:** monounsaturated fatty acid,
- **N:** number,
- **NS:** non-significant,
- **OP:** obesity prone,
- **OR:** obesity resistant,
- **PUFA:** polyunsaturated fatty acid,
- **PYY:** peptide YY,
- **REE:** resting energy expenditure,
- **RMR:** resting metabolic rate,
- **RO:** reduced-obese,
- **SD:** standard deviation,
- **SE:** standard error,
- **SEM:** standard error of the mean,
- **SFA:** saturated fatty acid,
- **TEE:** total energy expenditure,
- **TEI:** total energy intake,
- **TFEQ:** Three Factor Eating Questionnaire,
- **VLAD:** very low caloric diet,
- **VS:** visual analogue scale,
- **WC:** waist circumference.
association with obesity and then on what could be accurately investigated using
the resources, expertise, facilities and budget available to us.

2.5.1 Physiological Characteristics
One potential difference between those who struggle with their weight (OSI) and
those who remain lean with seeming ease (ORI) may involve appetite regulation.
Energy balance - the regulation of food intake, energy expenditure and body
weight (BW) is a homeostatic process [83]. The hypothalamus and the brainstem
are the main brain regions responsible for the regulation of energy homeostasis
[84]. Information about the current state of energy balance is transmitted to these
key brain regions by central and peripheral signals. Hunger and satiety are the co-
ordinated responses to these signals [83].

2.5.1.1 Hormone Concentrations
Several hormones have important roles in regulating energy homeostasis and
appetite. The body's largest endocrine organ, the gastrointestinal tract, releases
numerous regulatory peptide hormones including cholecystokinin, ghrelin,
peptide YY, pancreatic polypeptide, glucagon-like peptide 1 (GLP-1), and
oxyntomodulin, which influence short-term feelings of hunger and satiety [83-85].
In contrast, leptin and insulin are believed to be involved in the long-term
regulation of energy balance [84, 86]. A full review of the literature covering all
potential hormone influences and their mechanisms of action, in terms of appetite
regulation and energy homeostasis, is well beyond the scope of this thesis.
Detailed explanations can be found in several recent reviews on the topic [83-85,
87]. As there is such a breadth of literature, the following sub-sections focus on
describing the regulatory hormones that have been included in research within the
obesity resistance literature. Section 2.5.1.2 then outlines the findings from this
research in ORI compared to OSI.

2.5.1.1.1 Ghrelin
Ghrelin, discovered in 1999 and produced predominantly in the stomach [88], is
the only known orexigenic (stimulates appetite) gut hormone identified to date
Often referred to as the 'hunger hormone', plasma ghrelin levels are increased by fasting and decrease post-prandially in proportion to the amount of energy ingested [91-93]. Ghrelin is a strong appetite stimulator and appears to have an important role in meal initiation [85, 87, 91].

2.5.1.1.2 Peptide YY (PYY)
Peptide YY (PYY) is part of the PP-fold family of pancreatic polypeptides [85, 87]. Peptide YY is synthesised and released from L-cells throughout the length of the gastrointestinal tract, with the greatest concentrations found in the more distal parts [83, 84, 94]. The secretion pattern of PYY suggests this hormone plays a role in satiety. Circulating PYY levels are low in the fasted state and rise post-prandially in proportion to energy intake, reaching a peak after 1-2 hours, but remaining elevated for several hours [95, 96]. The reported effects of PYY involve the regulation of energy expenditure, delaying gastric emptying, reducing acid secretion, and inhibiting gallbladder contraction and pancreatic exocrine secretions [97, 98]. Peptide YY may also contribute to the 'ileal brake' - a negative feedback mechanism where the proximal intestine and gastric motor activity are inhibited due to the presence of nutrients in the colon, thereby protecting the distal intestine from large nutrient loads [85, 97, 99].

2.5.1.1.3 Glucagon-like Peptide-1 (GLP-1)
Similar to PYY, glucagon-like peptide-1 (GLP-1) is secreted by the L-cells of the gastrointestinal tract post-prandially in proportion to energy intake [84, 100]. There is also some recent animal evidence that suggests GLP-1 levels rise in anticipation of a meal [101]. As well as having an anorectic effect, GLP-1 also exerts incretin effects including increasing glucose-dependent insulin release, decreasing glucagon secretion and decreasing gastric emptying [102-104]. Again like PYY, GLP-1 also contributes to the 'ileal brake' [97].

2.5.1.1.4 Leptin
Leptin is the product of the ob gene and was first identified and cloned from rodent adipose tissue in 1994 [105]. Secreted predominantly by adipocytes [84, 87, 106],
leptin levels have a diurnal and pulsatile pattern, with peak levels occurring at night [107]. Centrally, leptin represents one of the fundamental components of the physiological system that maintains homeostatic control of BW in humans. Specifically, leptin works to signal states of negative energy balance and decreased energy stores [87, 108, 109] essentially to protect the individual from reductions in fat mass that could initially compromise reproductive function and in the long term, survival [108]. Peripherally leptin is involved in the regulation of both nutrient absorption from the gastrointestinal tract and the handling of lipid and glucose in adipose tissue, liver and skeletal muscle [106]. In light of the major functions of leptin, and the significant correlation between BMI or percent body fat and plasma leptin [110] one might expect that obese individuals would have low levels of this hormone. However, obesity is often associated with high levels of circulating leptin [84, 87, 106], which suggests there could be some resistance to its actions. Leptin resistance, a state in which the expected anorexigenic effects of leptin are greatly reduced, is a common feature of dietary induced obesity [106]. The main processes that appear to contribute to leptin resistance are a desensitisation of leptin receptor, down regulation of its intracellular signaling and inflammation [106].

2.5.1.1.5 Insulin
Insulin, produced in the β cells of the pancreas, is secreted rapidly post-prandially yielding well-known hypoglycaemic effects [111]. As with leptin, circulating levels of insulin are proportional to the degree of adiposity and the hormone is involved in the long-term regulation of energy balance [84, 87]. Furthermore, like leptin, increasing BMI is associated with insulin resistance, a state characterised by decreased insulin-mediated glucose transport in metabolically active organs and tissues (skeletal muscle, liver and adipose tissue) [112, 113]. However, the central effects of insulin on food intake and energy homeostasis may be less efficient than the effects of leptin [84].
2.5.1.2 Studies Investigating Hormone Concentrations in Obesity Resistant (ORI) and Obesity Susceptible Individuals (OSI)

Measurement of hormone concentrations has been undertaken in several studies comparing ORI and OSI [25-30, 38, 77]. However, for two of these studies the participants were not assessed under free-living conditions but instead the measurements took place under controlled dietary conditions before the implementation of overfeeding, underfeeding and eucaloric interventions [26, 30].

There appears to be only one study that has assessed concentrations of ghrelin, PYY and GLP-1 in a population representing ORI under *ad libitum* dietary conditions. Germain and colleagues [38] used female participants who exhibited constitutional thinness to represent obesity resistance. Following an overnight fast, hormone concentrations were measured every 4 h for a 24 h period in constitutionally thin individuals (CTI) compared to aged-matched control participants with BMI in the normal range. Fasting concentrations of ghrelin and GLP-1 were lower and PYY higher in CTI compared to normal weight controls. Similar results were observed in the 24 h hormone profiles for ghrelin and PYY, however, no difference was observed between CTI and normal weight controls for GLP-1.

Leptin concentrations have been assessed in a small number of studies using CTI as a proxy for individuals resistant to obesity [25, 27, 38, 77]. Bossu et al [77] and Germain et al [38] observed no difference in fasting leptin concentrations when comparing similarly defined CTI and control (normal BMI) participants and no difference in the concentration of leptin over a 24 h period. In contrast, Galusca and colleagues [27] observed lower fasting leptin concentrations in female CTI versus normal BMI controls (6.0 ± 0.8 vs 11.2 ± 1.9 μg.L⁻¹, P<0.05). Using comparable study groups, similar results for fasting leptin levels were also observed by Germain and colleagues [25] (CTI: 8.3 ± 1.4 vs Controls: 12.6 ± 0.9 μg.L⁻¹, P=0.04).

Fasting leptin concentrations have also been compared in lean versus reduced-obese participants [29, 30]. Following three days of a euenergetic weight-
maintenance diet, fasting leptin concentration was observed to be lower in lean compared to reduced-obese male and female participants (5.0 ± 1.5 and 1.2 ± 1.6 versus 18.2 ± 1.8 and 3.2 ± 2.0 ng.ml⁻¹, P<0.05; females and males respectively) [30]. Therrien and co-workers (2007) found a similar result among the lean male participants in their study who exhibited lower fasting leptin concentrations compared to reduced-obese and obese participants (P<0.001). However, amongst the female participants no difference in fasting leptin concentrations was observed between the lean and reduced-obese participants, although both groups did exhibit a lower fasting concentration of leptin than the obese participants (P<0.001) (data for both males and females is only available in a figure for this study).

In what appears to be the only study directly investigating fasting leptin concentrations in obesity resistant versus obesity susceptible individuals, Marrades et al [28] compared healthy young lean-resistant males (BMI<25 kg.m⁻²) to obese-susceptible males (BMI>30 kg.m⁻²) with similar high-fat intakes (>40% total energy intake (TEI)) and PA levels. Fasting leptin levels were observed to be lower in the obesity resistant group (8.3 ± 2.6 vs 33.3 ± 4.6 ng.ml⁻¹, P<0.001).

Two of the previously described studies have compared the fasting insulin concentration of ORI versus OSI [28, 30]. Marrades et al [28] reported a lower fasting insulin level in lean-resistant young men compared to obese-susceptible young men with similar high-fat intakes and PA levels (3.6 ± 0.1 vs 10.5 ± 3.1 μU.ml⁻¹, P=0.001). Similarly, Cornier and colleagues [30] also observed a lower fasting insulin concentration in lean compared to reduced obese individuals after 3 days of a euenergetic weight-maintenance diet (1.2 ± 1.6 and 4.3 ±1.6 versus 4.8 ± 1.1 and 6.1 ± 0.8 μU.ml⁻¹, P<0.05; males and females respectively).

2.5.1.2.1 Summary
The paucity of data regarding ghrelin, PYY and GLP-1 concentrations in ORI versus OSI makes it impossible to draw any conclusions relating to these hormones. From the limited available data it appears fasting insulin and leptin concentrations tend to be lower in obesity resistant compared to obesity susceptible groups. However,
within all of the studies presented above, no attempt has been made to control for BMI or body composition. This is important, considering leptin levels are highly correlated with adipose tissue mass in both males and females [110]. Without this adjustment, it is unclear whether the higher concentration of leptin in OSI reflects leptin resistance or more simply is a marker of greater adipose tissue mass in this group. In addition, Germain and colleagues [38] appear to be the only study to date where an attempt has been made to profile the hormonal response to a standardised meal in a group representing ORI without employing pre-test eucaloric dietary control.

### 2.5.1.3 Appetite Responses

The assessment of subjective appetite-related feelings is a widespread feature in appetite research. Appetite-related specific self-report scales commonly address some or all of the following somatic sensations, perceived general states of hunger/repletion, and motivation to eat:

- Feelings of hunger, fullness, satiety
- Prospective consumption (anticipated quantity that would or could be eaten)
- Desire to eat (or for a snack or meal)
- Urge to eat
- Thoughts of food
- Somatic sensations (eg emptiness or fullness of stomach)
- Desire for something sweet/savoury
- Thirst
- Nausea, gastrointestinal malaise or other side effects

[114]

Visual analogue scales (VAS), are one of the most widely used assessment systems for capturing self-reports of appetite-related feelings [114-117]. The VAS typically consist of a straight line, usually 100 or 150 mm, with two extreme states anchored at either end, for example ‘How full are you right now’?, ‘Not at all full’ at one end versus ‘as full as I have ever felt’ at the other end [115, 116]. Subjects indicate how
they feel at that moment with respect to each question by making a mark on the line. This is then quantified by measuring the distance from the left end of the scale to the mark. Scales are usually completed before (baseline) and after consumption of a test meal and then at regular time points (15 - 30 min, up to 1 h) for 3 – 5 h, or until the start of the next meal [114]. Visual analogue scales (VAS) are easy to design and use, simple to explain to participants and require minimal data handling and processing. For the analysis of appetite-related VAS, Blundell and colleagues [114] suggest using a repeated measures analysis or the area under the curve (AUC) rather than analysing data on individual time points that are not physiologically or statistically independent.

2.5.1.4 Studies Investigating Appetite Responses in Obesity Resistant (ORI) and Obesity Susceptible Individuals (OSI)

To date, the limited number of studies that have included an assessment of appetite responses in ORI versus OSI have all been conducted by the same research group working out of the Colorado School of Medicine. These assessments have all been undertaken as part of larger studies investigating the effects of short-term under- and/or over-feeding.

Thomas and colleagues [34] assessed appetite responses in obesity resistant and obesity prone individuals (groups defined based on a combination of self-identification, BMI and personal and family weight history). Participants initially consumed a eucaloric diet for three days, after which VAS were completed at 0, 30, 60, 90, 120, 150 and 180 min following the consumption of a eucaloric liquid breakfast meal. No differences in the AUC for hunger (‘How hungry do you feel right now?’), satiety (‘How full do you feel right now?’) or prospective food consumption (‘How much food do you think you could eat right now?’) were observed between obesity resistant and obesity prone participants. Using similarly defined participant groups and a comparable experimental protocol (which included the three days of eucaloric feeding prior to testing and the eucaloric liquid breakfast), Cornier et al [81] also observed no difference in fasting or AUC hunger responses assessed using VAS.
In an earlier, smaller study, the appetite responses measured by VAS of thin (BMI<23 kg.m\(^{-2}\)) versus reduced obese (mean BMI = 27.5 kg.m\(^{-2}\)) were compared before and after meals on days 6 and 7 of a eucaloric weight maintenance diet [31]. No differences in pre-meal hunger or prospective food consumption or post-meal satiety responses were observed between the thin and reduced obese individuals.

2.5.1.4.1 Summary
The evidence of comparable appetite responses in ORI compared to OSI is limited to a very small number of studies all of which have been conducted by the same research group under controlled eucaloric conditions. At present, as there appears to be no research documenting the appetite responses of ORI compared to OSI under free-living dietary conditions, it can only be speculated that similar results would be observed in this uncontrolled setting.

2.5.1.5 Sensitivity to Oral Fatty Acid Ingestion
Fat taste is an area of increasing interest in chemosensory and nutrition research. Our sense of taste is important in promoting either the acceptance or rejection of a food and recent research suggests that the detection of oral fat comprises a gustatory component [118, 119]. Sensitivity to fat may therefore play an important role affecting dietary habits and body energy balance. The intake and regulation of dietary fats is important especially given excessive consumption of dietary fat contributes to weight gain and obesity [120] and an acquired preference for high fat foods has also been associated with obesity [121]. It has been suggested that fat sensitive individuals have a reduced preference for high fat foods and therefore consume these foods less frequently [122]. This hypothesis is supported by a small number of recent investigations that have reported an association between hypersensitivity to fat and lower energy and fat intake, BMI and waist circumference (WC) [122-124]. Hypersensitivity to fat may therefore be one mechanism that allows some individuals to better regulate their BW.

A number of mechanisms have been proposed to explain the relationship between sensitivity to fat taste and fat intake, with the glycoprotein, CD36 appearing to play
a key role as a prime fatty acid taste receptor, especially when concentrations are low [125]. A full description of the literature covering the mechanistic action of CD36 is outside the scope of this thesis. For the most part, research examining the links between taste sensitivity and fat intake have been conducted in rodent models and cell culture studies with a scarcity of research in humans and the potential for inter-species differences [126].

2.5.1.6 Studies Investigating Sensitivity to Oral Fatty Acid Ingestion in Obesity Resistant (ORI) and Obesity Susceptible Individuals (OSI)

At this time, it appears no human studies have attempted to compare the oral fat sensitivity in individuals specifically defined as resistant or susceptible to obesity. Research is therefore limited to investigations using animal models. The literature relating to taste sensitivity and resistance to diet-induced obesity in rodent models has recently been summarised in a review by Ding and colleagues [74]. Compared with obesity prone rats, obesity resistant rats exhibit a lower expression of CD36 on the tongue and a slower increase in CD36 during the early response to a high fat diet [74]. CD36 knockout mice appear to be protected from gaining weight when consuming a high fat diet and show decreased preference for fat, decreased food intake, BW and adiposity [74]. Given the association between dietary fat intake and obesity and the promising results seen using animal models, it would clearly be of interest to conduct studies in humans to determine whether a link exists between obesity resistance and sensitivity to fat.

2.5.2 Metabolic Characteristics

2.5.2.1 Resting Metabolic Rate (RMR)

Resting metabolic rate (RMR) (sometimes referred to as resting energy expenditure) or basal metabolic rate (BMR) represents the largest component (around 60-75%) of total daily energy expenditure in sedentary humans [127]. This is the energy required to sustain vital functions such as heart beat, respiration and thermoregulation and is expressed as kcal.d⁻¹, kJ.d⁻¹ or MJ.d⁻¹ [128]. Both RMR and BMR can be measured by direct or indirect calorimetry [129], although indirect methods are more often used with free-living individuals. Resting metabolic rate (RMR) is measured in a semi-recumbent/supine position in a
physically comfortable test site (e.g., quiet and thermo-neutral) following an overnight fast and avoidance of caffeine, nicotine, alcohol and strenuous exercise and controlling for menstrual cycle phase [130]. The more restrictive measurement of BMR includes similar controls to the RMR measurement described above, but also requires the participant to sleep overnight in the test site as BMR is measured upon waking after 8 hours sleep [129]. Despite these differences in measurement conditions, RMR is generally within 10% of BMR [129] and in practice the terms are often used interchangeably [131].

Previous research has demonstrated that obese individuals have an increased absolute BMR compared to their lean counterparts [132-136]. The increase in BMR is mainly due to an increase in fat-free mass (FFM), which increases alongside the fat mass [135, 137]. Resting metabolic rate (RMR), when expressed as an absolute measured value, has little applicability for comparing individuals or groups of differing body mass and composition. Therefore, measured RMR is often expressed relative to body size and/or composition in an effort to reduce the variability between individuals and improve accuracy [138]. When expressed relative to FFM most studies find similar BMRs between lean and obese subjects (Prentice, 1989). For individuals with a high BMI, both FFM and fat mass make significant contributions to total body mass, so for this population total body mass has been shown to be better correlated with RMR than FFM alone [139, 140].

Initially, the results of studies comparing the RMR of formerly obese individuals compared to matched never-obese controls tended to show no difference [137]. Many of these studies used a small sample size (6-12 subjects in each group) and therefore lacked statistical power to detect differences in RMR <10-15%. However, a meta-analysis of 12 published studies undertaken by Astrup and colleagues [141] concluded formerly obese individuals had a 3-5% lower mean relative RMR than control subjects. Subsequent research suggests RMR is suppressed in conjunction with weight loss, often to a greater degree than would be expected based on changes in BW/body composition [142, 143]. This is known as adaptive thermogenesis or metabolic adaptation - an adaptive response that reduces energy expenditure to effectively oppose the maintenance of a reduced BW [144, 145].
The mechanism/s responsible for metabolic adaptation to weight loss are still unclear but likely involve co-ordinated action of the metabolic, neuroendocrine and autonomic systems [144, 145]. A lower (or suppressed) RMR is likely to contribute to the high rate of weight regain in obese persons after weight loss [143]. It would therefore be of interest to compare the measured RMR of obesity resistant individuals who easily maintain a healthy BW with obesity susceptible individuals who struggle with weight maintenance.

2.5.2.1.1 Prediction Equations to Estimate Resting Metabolic Rate (RMR)

An evaluation of energy requirements is a necessary part of a complete individual nutritional assessment. If the goal is weight reduction, then achievable targets need to be established in terms of BW and dietary intake, which requires knowledge of individual energy requirements. Although direct and indirect calorimeters are standard tools to assess RMR in research settings, due to the expense of calorimeters, the time needed to achieve an accurate measurement, and the need for trained personnel to run the tests, the measurement of RMR for individual patients/clients in a clinical setting is relatively uncommon [128, 146, 147]. Instead, the use of predictive equations developed through regression analyses using calorimetry as the criterion measure and various characteristics of the individual such as body mass, height, sex and age [128, 146, 148], is standard in dietetic practice [149, 150]. There are many, varied equations available - a recent review identified 248 BMR estimation equations [131]. Well-known examples of these include: the Harris-Benedict [127], Weir [151], FAO/WHO/UNU (Food and Agricultural Organisation/World Health Organisation/United Nations University) [152], Miflin-St Joer [153], and Oxford [154].

Considerable debate surrounds the best equation for predicting metabolic rate in any particular setting, particularly in overweight or obese individuals [128, 131, 146-148, 155]. Because of the way they are generated, predictive regression equations work best in groups of people [146]. When these equations are applied to an individual (eg use of RMR equations to predict energy requirements in clinical dietetic practice), errors large enough to impact outcome could be produced, especially if the individual does not share important characteristics with
the group from whom the equation was developed (eg age, sex, body composition, ethnicity etc) [146]. It would therefore be interesting to compare the ability of commonly used equations to predict RMR in individuals specifically defined as resistant or susceptible to obesity.

2.5.2.2 Studies Investigating Resting Metabolic Rate (RMR) in Obesity Resistant (ORI) and Obesity Susceptible Individuals (OSI)

Resting metabolic rate (RMR) has been assessed in a number of studies where comparisons have been made between ORI and OSI. For over half of these studies, RMR was only measured in order to estimate energy expenditure for the subsequent calculation and creation of eucaloric, under- and over-feeding diets and the results were not presented [26, 32-34, 78, 79]. Resting metabolic rate data has been published comparing CTI with normal BMI controls [25, 77], lean/thin with reduced obese [30, 31] and lean-resistant participants with obese-susceptible individuals [28].

Using only male participants, Marrades and co-workers (2007) found a lower absolute RMR in lean-resistant compared to obese-susceptible participants (16.2% difference, P<0.0001). Similarly, Germain et al [25] and Bossu et al [77] also observed a lower absolute RMR in female CTI compared to normal BMI controls (16.2% and 13.2% difference, P<0.05; respectively). In contrast, when male and female data were combined no differences in absolute RMR were observed between lean/thin and reduced obese individuals [30, 31].

Few of the studies discussed above have reported RMR expressed relative to BW or body composition. While Germain et al (2014) and Bossu et al [77] found a lower absolute RMR in female CTI versus controls, when expressed relative to BW this difference disappeared [25] and when expressed relative to FFM, CTI had a higher RMR than controls [77]. Marrades and colleagues [28] observed that the lower absolute RMR in male lean-resistant compared to obese-susceptible individuals disappeared when RMR was adjusted for fat mass and FFM (5.59 ± 0.97 vs 5.61 ± 0.13, P=0.905; respectively).
To the candidate’s knowledge, no studies to date have attempted to compare the ability of predictive equations to estimate RMR in ORI versus OSI.

2.5.2.2.1 Summary

It is difficult to draw any strong conclusions from the RMR data comparing individuals resistant and susceptible to obesity due to the small number of studies and large differences in the definition of obesity resistance and susceptibility. One observation that does perhaps deserve attention is the issue of sex. A significantly lower absolute RMR was observed in CTI/ORI compared to normal weight controls/OSI in the three studies that only included females or males [25, 28, 77]. Whereas, no difference in absolute RMR was observed in the studies that included both male and female participants within the obesity resistant and susceptible groups [30, 31]. Absolute RMR is higher in males than females most likely because of differences in FFM and fat mass [156-159]. It would therefore be prudent that an adjustment for sex, to account for sex-specific differences in body composition, needs to be considered when analysing RMR data in studies that include both sexes in their comparison groups.

2.5.3 Dietary Intake

One of the key potential consequences of living in an obesogenic environment is the consumption of energy in excess of needs. Possible factors that promote this overconsumption include the easy availability of an unlimited variety of palatable, inexpensive, energy-dense foods and drinks served in large portions, promoted aggressively to consumers [9, 10, 12, 58, 67]. By definition, therefore, dietary intake must play an important role in the aetiology of obesity. Many studies have described trends in dietary intake and linked this to the increasing prevalence of obesity [160-163]. In an attempt to identify the specific dietary determinants of obesity, much attention has been paid to total energy intake, to the intake of individual macronutrients and their constituents and to the intake of certain foods and food groups.
2.5.3.1  **Energy and Energy-Yielding Nutrients**

Energy density has received particular focus as one of the dietary factors suggested to play an important role in the regulation of energy intake [164, 165] as small changes in the energy density of the diet could lead to large changes in energy intake, if the quantity of the food consumed remains unaltered [166]. Energy density is the amount of energy in a particular weight of food and is generally presented as the number of calories (or kilojoules) per gram of food (kcal.g\(^{-1}\) or kJ.g\(^{-1}\)) [165]. Water lowers the energy density of foods as it contributes weight but not energy [165]. Evidence from short-term studies suggests lowering dietary energy density reduces energy intake, however, the data on long-term effectiveness for weight loss is currently insufficient, due to the small number of studies and heterogeneous intervention protocols [166].

2.5.3.1.1  **Fat**

Dietary fat intake has been given considerable attention as a potential factor associated with obesity for a number of reasons. Due to the high energy content, fat (37 kJ.g\(^{-1}\)) influences energy density more than CHO (16 kJ.g\(^{-1}\)) or protein (17 kJ.g\(^{-1}\)), consequently, foods with a high fat content generally have a high energy density [165]. Compared to CHO or protein, fat is readily stored as body fat, with minimal energy costs of conversion [167] and has a weak satiating effect [167, 168]. In many foods taste, aroma, and texture are improved by fat and these palatability-enhancing effects have the potential to stimulate overconsumption [120, 168]. Further, increases in the palatability of the food supply have been linked to increasing weight in the population [169]. Some of the components of total fat intake may have variable effects on obesity. A high monounsaturated fatty acid (MUFA) or polyunsaturated fatty acid (PUFA) diet appears to be more metabolically beneficial compared to a high saturated fatty acid (SFA) diet in terms of energy expenditure and weight maintenance [170].

2.5.3.1.2  **Carbohydrate (CHO)**

There is a significant amount of debate related to the optimal amount of dietary CHO that should be consumed with respect to obesity prevention or treatment.
The proportion of CHO tends to vary reciprocally with fat to the extent that it is difficult to separate the impact of the total amount of CHO from the total fat in the diet [167]. In general, low CHO restricted calorie diets have been shown to induce weight loss to at least the same extent over the long term (up to 2 years) as their low fat counterparts [171, 172]. A number of constituents of CHO have also received attention regarding their efficacy in promoting weight loss/maintenance or contributing to weight gain.

2.5.3.1.3 Dietary Fibre
Simply put, dietary fibre is the undigested CHOs in the diet [173]. Soluble fibre (pectins, gums, inulin-type fructans and some hemicelluloses) dissolve in water forming viscous gels, bypass digestion in the small intestine and are easily fermented by the microflora of the large intestine [174]. In contrast, insoluble fibre (lignin, cellulose and some hemicelluloses) are not water soluble, do not form gels and fermentation is very limited [174].

Increasing dietary fibre generally has a favourable effect on BW [167, 174]. This is accomplished via multiple potential mechanisms including: i) dietary fibres reduce the energy density of foods which may lead directly to reduced energy intake; ii) high-fibre foods generally take longer to chew which may increase sensory satiety and decrease meal size; iii) fibre-rich foods may also enhance satiety via delayed gastric emptying; and iv) dietary fibres may decrease energy absorption by lowering the bioavailability of fatty acids and proteins [167, 175]. The inhibitory effects of fibre-rich diets are thought to depend on the chemical structure of the fibre and their physiochemical properties (solubility, viscosity, water-holding capacity and fermentability) rather than on total fibre intake [176].

2.5.3.1.4 Sugar
Sugars may be classified as ‘naturally occurring’ or ‘added’. Added sugars are defined as sugars or syrups added to foods during processing or preparation, including those added at the table [177]. When consumed under isoenergetic conditions, current research suggests there is little evidence of a direct linkage
between sugar consumption and BW [177-179]. However, modifying the current intake of dietary sugars (increase or decrease) from current levels of intake is associated with corresponding changes in BW in adults [179]. The most likely mechanism by which increasing dietary sugar may have in facilitating weight gain is by contributing to energy consumption above energy needs [179]. In recent years, fructose and fructose-containing sugars have come under scrutiny as the consumption of these sugars has increased markedly over the last 30 years, seemingly in parallel with the rise of the obesity epidemic. This is mainly due to consumption of sucrose or high-fructose corn syrup in processed foods and beverages [180]. As with dietary sugar, the evidence suggests that any role fructose-containing sugars have in the development of obesity is mainly by contributing to increased total energy intake [180-182]. The relationship between sugar-sweetened (SS) beverages and weight gain is addressed separately in section 2.5.3.2.6.

2.5.3.1.5 Protein
Accumulating evidence suggests that a high proportion of dietary energy from protein may translate into beneficial effects on BW and composition over time [183, 184]. These favourable effects appear to be due to increased diet-induced thermogenesis, increased satiety and decreased hunger [183-185]. In addition, higher dietary protein intakes (1.2-1.5 g.kg\(^{-1}.d^{-1}\)) have been reported to preserve lean body mass and improve body composition when consuming energy-restricted diets in young, middle-aged and older adults [186, 187].

2.5.3.1.6 Alcohol
Research evidence linking alcohol intake and obesity is often difficult to interpret due to differences in the responses observed between males and females, the type of alcoholic beverage consumed and between moderate compared to heavy drinkers [188]. There are a number of reasons why alcoholic beverages could be implicated in weight gain and obesity. Firstly, alcohol provides energy (29 kJ.g\(^{-1}\)), making it second-only to fat in terms of energy density; secondly, it cannot be stored by the body so takes priority for oxidation compared to fat and CHO; thirdly,
energy ingested in fluid form may be poorly compensated for in current or subsequent food intake, leading to passive overconsumption of energy; and finally alcohol ingestion may disrupt certain receptors and hormones involved in the control of feeding [188, 189].

2.5.3.2 Specific Foods and Food Groups
Humans do not eat nutrients per se – we eat food. Therefore, it is not surprising a variety of specific foods and food groups have been associated with obesity, either from a potentially causative or protective standpoint, as they represent a significant source of certain nutrients or exhibit other pro- or anti-obesogenic properties.

2.5.3.2.1 Fruits and Vegetables
In general, fruits and vegetables are rich in water and fibre, and low in energy density and it is because of these properties that increasing fruit and vegetable consumption has been proposed as an obesity prevention strategy. Specifically, the consumption of fruits and vegetables may displace other energy-dense foods, the satiating effect of fibre may result in less energy being consumed and the fibre content may also reduce energy absorption from the gastrointestinal tract [173, 190-192]. Current evidence suggests that increasing fruit and vegetable intake may contribute to weight stability but does not result in weight loss unless they replace foods rich in fat or energy [190, 191].

2.5.3.2.2 Whole grains
Diets high in whole grains have also been proposed to impart a protective effect with regard to weight control. The main mechanisms suggested to be supportive of this effect relate to the higher fibre content of diets rich in whole grains and that whole grain foods generally have a lower energy density [193, 194]. The most commonly consumed whole grains worldwide are wheat, brown and long-grain rice, maize, oats, barley, rye, millet, sorghum, and triticale [195]. There is epidemiologic evidence that a diet high in whole grains is associated with a lower BMI, smaller waist circumference (WC) and reduced risk of being overweight [193,
194, 196, 197]. However, the relationship is less clear when reviewing the results of intervention trials [193, 196]. This may be due to the following factors: there are few well-controlled studies specifically examining the effect of high intakes of whole grains on weight reduction or maintenance in the long term; there are varying definitions of what constitutes a whole grain food; and people who eat whole grains may be more likely to make other healthy lifestyle choices, which confound the results [196, 197].

2.5.3.2.3 Dairy Products
Diets high in dairy products may also enhance weight management. Dairy contains multiple bioactive components including calcium, lactose, proteins (in particular whey proteins), and their peptide derivatives, which have been proposed to have effects on lipid metabolism (calcium) and regulation of food intake and satiety [198-200]. Data from observational studies show a modest but significant inverse association between dairy product consumption and BW gain [199, 201]. Evidence from clinical trials suggests the effects of dairy consumption on weight loss are only apparent when combined with an energy-restricted diet and that this combination may enhance the positive effects on weight, body fat, lean mass and WC compared with energy-restriction alone [198, 202].

2.5.3.2.4 Nuts
Nut consumption has been associated with several health benefits related to the antioxidant, cardioprotective, hypocholesterolaemic, and anti-inflammatory properties of nuts [203]. However, because nuts are energy-dense foods with a high fat content there is a widespread perception that increased consumption may lead to BW gain and risk of developing obesity [203-206]. Epidemiological studies, short-term feeding trials and controlled clinical trials have shown no association with a higher risk of weight gain [203, 204, 207]. In fact the available evidence suggests long-term nut consumption is associated with stable or low BW gain [203, 205, 206]. There are three reported mechanisms whereby nuts may assist with weight control. Firstly, the protein and fibre content of nuts increases satiety;
secondly, the incomplete digestion of whole nuts results in fecal fat loss; and finally, there is an increase in RMR due to the high unsaturated fat content [204].

2.5.3.2.5 Fast Foods
Although not necessarily agreed upon, fast foods can be defined as ‘easily prepared processed food served in snack bars and restaurants as a quick meal or to be taken away’ [208]. There are several factors inherent to fast foods that could increase the risk of weight gain and obesity in regular consumers, by promoting positive energy balance including: large portion sizes, high palatability (high fat and sugar content) and high energy density [209-212]. A positive association between consumption of fast food meals and BMI or being overweight has been observed in cross-sectional and longitudinal studies [213]. In addition, eating at fast food outlets has been shown to positively predict weight change and the weight gain associated with frequent fast food use is potentially higher than for restaurant use [210].

2.5.3.2.6 Sugar-Sweetened (SS) Beverages
The trend of a rapid rise in the intake of added sugar in the past 3 to 4 decades, which parallels the rise in obesity rates, has largely been driven by the dramatic increase in the consumption of SS beverages [214]. Examples of SS beverages include carbonated beverages (sodas or soft-drinks), fruit drinks, enhanced waters, highly sweetened coffees and teas, sports drinks and energy drinks, typically sweetened with high-fructose corn syrup or sucrose [215]. Plausible physiological mechanisms exist linking consumption of SS beverages with weight control. Energy-containing beverages may elicit weaker satiety and compensatory dietary responses than solid food [216-218], potentially increasing the total energy intake and the risk of weight gain [189]. Recently it has been reported that New Zealand adult consumers of SS beverages aged 19 – 30 and 31 – 50 years consume on average 51 g and 26 g, respectively, of total sugar from SS beverages [219], suggesting SS beverages make a significant contribution to total sugar intake in the diets of consumers.
A number of meta-analyses and reviews of published studies have attempted to evaluate the association between SS beverage consumption and energy intake, weight gain, adiposity, BMI and incidence of being overweight or obese, with mixed results [220-222]. This may be due to the different outcomes measured and varying inclusion criteria of the studies [221, 222], the lack of a clear description of the study protocols [223], or even potentially the source of sponsorship of the review (eg industry-funding) [220]. Although not a universal finding in all studies, the available evidence to date supports a pattern across observational, prospective, and intervention studies of an increased risk of weight gain and obesity with higher intakes of SS beverages [189, 214, 221, 224]. Meta-analyses of randomised control trials appear to support a dose-dependent increase in BW gain [221, 225] but this appears somewhat less than would be predicted if consumption of SS beverages provoked no compensation within other components of the diet [225]. Therefore, although there appears to be some compensation for the liquid energy in SS beverages, without full compensation there is a risk of gradual adiposity ‘creep’ and subsequent weight gain [189].

2.5.3.3 Studies Investigating Energy and Nutrient Intake in Obesity Resistant (ORI) and Obesity Susceptible Individuals (OSI)

Within the limited body of literature comparing ORI and OSI, there are a small number of investigations where dietary intake data has been collected [25, 28, 30-32, 38, 77]. However, for nearly half of these studies the dietary intake results were not reported, as this data was only obtained to assist with estimating daily energy needs prior to implementing overfeeding, underfeeding and eucaloric dietary interventions [30-32]. To date, there are only four published studies where direct comparisons of dietary intake data have been made between lean-resistant and obese-susceptible individuals [28], or CTI and normal weight controls [25, 38, 77].

As part of their research investigating the role of macronutrient oxidation ability in the postprandial response to a high lipid load, Marrades et al [28] collected three day weighed diet records from leanresistant and obese-susceptible healthy young males. By design, all participants had similar habitual high fat intakes (>40% total
energy intake (TEI)) and comparable PA levels. Dietary intake data was obtained
by a 5 day ‘dietary daily self-reporting record’ [25] and 4 day estimated diet
records [38, 77] in the three studies where CTI were compared to normal weight
controls.

The results of all four studies showed no difference in any measured dietary intake
variable when lean-resistant or CTI were compared to obese-susceptible or
normal-weight controls. Specifically, Marrades et al [28] found no differences in
intakes of energy, total fat (g), fat (%TEI), saturated fat (SFA), monounsaturated fat
(MUFA), polyunsaturated fat (PUFA), carbohydrate (CHO) (g), CHO (%TEI), fibre,
protein (g) or protein (%TEI) in lean-resistant high fat (>40 %TEI) consumers
versus obese-susceptible high fat consumers. While no differences were found
amongst CTI versus normal weight controls for the intake of energy [25, 38, 77],
total fat (g) [25], CHO, fat or protein as a percentage of TEI [25, 77] or SFA, MUFA
or PUFA as a percentage of total fat intake (TFI) [25].

To date, it appears no studies have been published investigating specific foods or
food groups in individuals resistant to obesity compared to those susceptible to
obesity.

2.5.3.3.1 Summary
Although a consistent finding of no difference in dietary intake was observed in all
the studies presented above, it would be premature to conclude that there are
indeed no dietary intake differences in ORI compared to OSI. Besides the fact that
there are only a small number of studies, within those studies, only a limited
number of dietary intake variables have been assessed within a small number of
participants (≤10 per group). In addition, only Germain and colleagues [25]
performed an evaluation to check for the presence of low energy reporting – a
common and acknowledged source of measurement error in dietary assessment
[226, 227] with perhaps particular relevance to these groups under study.
2.5.4 Physical Activity (PA) and Sedentary Behaviour

The other key potential consequence of living in an obesogenic environment is a reduction in PA and an increase in sedentary behaviours that reduce total energy expenditure and further exacerbate the energy imbalance.

2.5.4.1 Physical Activity (PA)

Physical activity (PA) is defined as “any voluntary body movement generated by the contraction of skeletal muscles resulting in energy expenditure” [228]. Participating in regular PA is associated with numerous health benefits and reduction in the risk of developing chronic diseases such as type 2 diabetes, cardiovascular disease, some types of cancer, hypertension, osteoporosis, depression and dementia [229-231].

There is evidence to support the link between progression of the obesity epidemic and secular changes in PA from multiple domains, including occupation, the household and transportation [232-234]. Most [235, 236], although not all [237] researchers agree increases in energy consumption coupled with changes in population levels of PA over time have produced the obesity epidemic in developed countries. However, the strength of evidence of the role changes in PA has had in the emergence of the obesity epidemic are relatively weak as there is a lack of longitudinal population-based studies incorporating objective measures of PA across the time-frame associated with the development of the epidemic [235].

Participation in regular PA appears protective against adverse changes in BW. Results from several longitudinal observational studies suggest an inverse relationship between PA and weight gain [238-242]. Conversely, weight gain is often associated with a decrease in PA [243-246]. This suggests that PA and weight gain may actually have a complex bi-directional relationship [247-249].

Lifestyle intervention that focuses on inducing and supporting a negative energy imbalance forms the basis of obesity management worldwide [250, 251]. Caloric restriction is widely viewed as the most important component in achieving weight loss through negative energy balance [251]. However, results from randomised
control trials indicate that increasing PA to levels eliciting the same energy deficit as diet-only interventions, can be equally effective [252-254]. To ensure compliance, the PA that is included in these types of interventions often takes place under structured and/or supervised conditions. Individuals who receive supervised exercise training have shown a greater decrease in BW compared to controls who receive no advice regarding exercise training [255]. This, combined with the fact that the amount of PA needed to produce the necessary negative energy imbalance, may make it difficult for the already overweight/obese to implement in the long-term [250, 251, 256].

It is clear that PA has a role to play in the treatment and management of obesity. Recent reviews and meta-analyses conclude that at equivalent energy reductions, the combination of exercise and modest calorie restriction is more effective for weight loss than calorie restriction alone [257-259]. In addition, although not necessarily effective in producing significant weight loss, there is some evidence indicating resistance training may increase the ratio of FFM to fat mass [260]. Equally important, PA has been shown to be effective in reducing the weight regain that tends to occur after weight loss [261]. Studies have shown that individuals who exercise frequently following a period of weight loss are less likely than non-exercisers to experience weight regain [262-264]. Also during the weight regain period those individuals who include some resistance training in their PA routine are likely to accumulate less of their regained weight as fat [265].

As a result of the identified link between PA and reduction of the risk of developing numerous NCD, such as type 2 diabetes, hypertension, cardiovascular disease, osteoporosis and obesity, various national [266, 267] and international guidelines [268] have been established to promote engagement in PA at the population level. Typically these guidelines include weekly recommendations of 150 min of moderate-intensity activity or 75 min of vigorous-intensity activity, or some combination of moderate and vigorous activity with 2 days of resistance exercise.
2.5.4.2 Sedentary Behaviour

Sedentary behaviour is now recognised as not simply the absence or the low end of the PA continuum, but as a separate and unique construct [269, 270]. The term 'sedentary' refers to a distinct set of behaviours undertaken during waking hours such as sitting, lying down, working at a computer, driving, and watching television or other forms of screen-based entertainment, that typically involve minimal body movement and low levels of energy expenditure (≤ 1.5 Metabolic Equivalent of Task (MET)) [270-272].

Sedentary behaviour is associated with adverse health outcomes that may differ from those attributed to a lack of moderate to vigorous PA [270]. A recent overview of systematic reviews investigating the association between sedentary behaviour and health outcomes described the relationship as complex and dependent on the type of sedentary behaviour and age group studied [273]. Specifically, for adults, the authors found strong evidence of a relationship between sedentary behaviour and all-cause mortality, fatal and non-fatal cardiovascular disease, type 2 diabetes and metabolic syndrome and moderate evidence for incidence rates of ovarian, colon and endometrial cancers [273].

With respect to obesity risk, data from adults show an association between weight status and sedentary behaviour. For example, for each 2 h per day increase in television viewing, a 23% increased risk of developing obesity was observed after 6 years in the Nurses’ Health Study [274]; while in another large study of women, elevated levels of leisure time sitting were associated with increased risk of weight gain [275]. By definition, increased time spent engaging in sedentary pursuits would result in a decrease in total energy expenditure, increasing the potential risk of weight gain. In addition, data from mostly cross-sectional studies indicate that sedentary behaviour is associated with an unhealthy diet (less fruit and vegetable intake and greater consumption of energy-dense snacks and SS beverages) especially in young people [276, 277]. Hence, there is the potential to further exacerbate energy imbalance through this combination of increased energy intake and reduced total energy expenditure induced by sedentary behaviours.
Various interventions designed to target sedentary behaviour in children, adolescents and adults have shown success in reducing this deleterious activity [278, 279]. In a number of studies, the effectiveness of reducing sedentary behaviours has also resulted in improvements in BW indices in children and adolescents [280, 281] with the greatest improvements observed in the overweight and obese populations [282]. Unfortunately, comparable investigations in adults are limited, although positive effects of breaks in sedentary time have been seen on measures of WC and BMI [283].

2.5.4.3 Measurement of Physical Activity (PA) and Sedentary Behaviour

Physical activity (PA) and sedentary behaviour can be measured using a variety of subjective and objective methods. Subjective methods include diaries, activity logs, recalls and questionnaires [228, 270, 284], while objective methods include the use of heart rate monitors, pedometers, indirect and direct calorimetry and accelerometers [284-286]. Different techniques within both forms of measurement methods have potential advantages and limitations when it comes to assessing PA and sedentary behaviour. For the sake of brevity the following sections (2.5.4.3.1 and 2.5.4.3.2) have been limited to describing the measurement techniques used to date in the obesity resistance literature and in data collection for this thesis. A comprehensive description and review of other methods to assess PA and sedentary behaviour can be found in a recent historical perspective on the topic [284].

2.5.4.3.1 Subjective Measurement Techniques

Self-reported physical activity questionnaires (SRPAQ) are relatively inexpensive and easy to administer and as such have proven popular in the assessment of PA in large-scale studies [284, 286, 287]. There are numerous questionnaires described in the literature, including: the International Physical Activity Questionnaire (IPAQ) long and short forms [288]; the Recent Physical Activity Questionnaire [289]; the Global Physical Activity Questionnaire [290]; the Physical Activity Assessment Tool [291] and the Active Australian Survey [292].
Many historical SRPAQ are rather simple and tend to reduce PA to a ranking between individuals who are ‘sedentary’ and those who are active [284, 286, 293]. But PA is a complex multidimensional behaviour that takes place in a variety of domains including occupation, domestic life, transportation and recreation [285, 294]. Now, many SRPAQs are designed to enable assessment of these multiple dimensions of PA by asking for information on the type, location, domain and context of the activity and for estimates of time spent in activities of various levels of intensity [295].

The major limitation of SRPAQ is the level of error associated with quantifying the dose or absolute volume of PA undertaken [228, 293]. This measurement error and bias is often due to cognitive limitations related to recall of the activity and actual comprehension of the questionnaire [296, 297]. Also, while some SRPAQ may be able to assess some aspects of moderate-intensity and vigorous-intensity physical activity (MVPA), most researchers agree that SRPAQ are less accurate than objective measures for estimating MVPA and PA energy expenditure [284, 286, 294].

When it comes to measuring sedentary behaviours, SRPAQ also have limitations. Unlike volitional physical activities that can be more easily remembered and described (eg rugby game, bicycle ride, gym class), sedentary pursuits (eg television viewing, attending a meeting, talking on the phone, lying on the couch etc) occur in a varied and sporadic manner throughout the day, often interspersed with periods of light activity [270]. The quantification of sedentary behaviour in SRPAQ is therefore often undertaken using proxy measurements eg car time, chair time, screen time or sitting time [270]. Although this information can be informative, these individual behaviours are not necessarily representative of all sedentary pursuits that have occurred throughout the day [298].

2.5.4.3.2 Objective Measurement Techniques
Ideally PA should be measured with objective techniques in free-living conditions, for a period of time that represents the habitual activity level, with minimal discomfort to the participant, using unobtrusive inexpensive data collection
systems [228]. Due to their ability to reasonably satisfy these specifications, pedometers and accelerometers have been widely used in research requiring the assessment of PA and more recently, sedentary behaviours.

Accelerometers are small electronic motion-sensing devices that are generally worn on the hip, which allow detailed data on the volume and intensity of most movement to be captured and downloaded for later analysis [286, 299]. The raw acceleration signal captured by the accelerometer is converted to a generic measure of activity intensity called ‘counts’ which are strongly correlated with energy expenditure and can provide an indication of PA intensity [285]. Pedometers are a cost-effective alternative to accelerometry. Worn predominantly on the waist or hip, pedometers count each step an individual takes and can be used to estimate distance travelled or energy expended [285]. However, because of their more simplistic design, pedometers are unable to consider the magnitude of the movement detected [285]. A step is registered for any movement above a given threshold, whether that movement was generated during walking, running or jumping.

Rather than relying on information provided by the participant, objective measures such as pedometers and accelerometers, record the real time biomechanical consequences of performing PA. Therefore they are not subject to the reporting bias or recall issues associated with SRPAQ [285]. Other advantages of accelerometers are that although the devices are small, they can record data continuously over an extended period of time in relatively short time increments (epochs) (eg 15, 30 or 60 s) [272, 300]. By applying cut-points, accelerometry also allows researchers to determine cumulative time spent each day at all intensity levels, including sedentary, light, moderate and vigorous [270, 272]. Being able to quantify the amount of time an individual spends below a given intensity cut-point enables calculation of total sedentary time, thus overcoming the limitations associated with assessing sedentary behaviour using SRPAQ [270].

Although accelerometers allow for more robust assessments of movement behaviours than SRPAQ, these measurement tools do have their limitations.
Accelerometers are typically worn on the hip and primarily measure locomotor activity (or lack of), so are unable to capture upper body movement or distinguish if an individual is carrying any load (e.g., a heavy bag) [301]. In addition, accelerometers (and pedometers) are unable to account for the increased energy cost associated with walking up an incline or stairs [270, 285, 286] or to distinguish between sitting and standing still [301], potentially leading to an underestimation of total PA.

As previously described, accelerometer count cut-points are required to convert raw accelerometer count data to a form that can be interpreted. At present there is no general consensus on what cut-points should be used [286]. However, it is clear that different thresholds are required to distinguish between sedentary, light, moderate and vigorous intensity PA depending on the type of accelerometer used and the age of the participants [302]. Finally, unlike SRPAQ, accelerometers and pedometers are unable to capture contextual information about the types of sedentary pursuits or PA the individual has engaged in, or to determine patterns of activity [228, 270].

2.5.4.4  Studies Investigating Physical Activity (PA) in Obesity Resistant (ORI) and Obesity Susceptible Individuals (OSI)

There is a paucity of research comparing PA levels in ORI and OSI. At present, there are only three studies in which an attempt has been made to evaluate PA in these two groups [25, 77, 82].

Germain and colleagues [25] collected baseline activity-induced energy expenditure (AEE) data using accelerometers worn for 5 d in eight female CTI versus eight age-matched normal weight controls and found no difference in AEE (kJ.d⁻¹) between the two study groups. Bossu et al [77] also used constitutional thinness to represent obesity resistance. As part of their study evaluating energy metabolism, Bossu et al [77] assessed energy expenditure due to PA using the MONICA Optional Study of Physical Activity Questionnaire (MOSPA-Q). In addition, AEE was estimated from total energy expenditure, measured using doubly labeled
water, and RMR. The authors reported no differences in either measure of PA between seven female CTI and seven age-matched normal-weight controls.

The only study to date directly comparing the PA level of ORI and OSI was conducted by Schmidt and colleagues [82]. The primary aim of this investigation was to determine if spontaneous PA responded differently to short-term (3 d) overfeeding in ORI and obesity prone individuals. During baseline data collection, 32 ORI (16 female and 16 male) and 23 obesity prone (15 female and 8 male) participants wore pedometers for 1 week. No differences in the number of steps taken per day (mean ± SD) were observed between ORI and obesity prone individuals (9082 ± 501 versus 9984 ± 608, respectively; p=0.26).

As with other areas of potential importance in weight control, to the candidate’s knowledge, there have been no studies conducted thus far that have attempted to compare sedentary behaviour or adherence to PA guidelines in ORI versus OSI.

2.5.4.4.1 Summary
With so little research comparing PA variables between individuals resistant to obesity and those susceptible to obesity, no conclusions can be drawn relating to differences or similarities in the amount or level of PA undertaken by these two groups. In addition, the few studies that have been conducted have limited ability to actually detect any relationships between activity level and resistance or susceptibility to obesity due to the small number of participants in each group. Along with comparative assessments of sedentary behaviour and adherence to PA guidelines, this is an area of research in need of further investigation.

2.5.5 Eating Behaviour
Eating behaviour involves the complex interaction of physiological, psychological, social and genetic factors that influence meal timing, quantity of food intake, food preference and food selection [303]. Eating behaviours influence energy intake through choices about when and where to eat, the types and amounts of food chosen, including decisions about starting and stopping eating [76, 304]. Several
eating behaviour dimensions have been described for both children and adults in the eating behaviour and obesity literature. These include: food responsiveness, food enjoyment, satiety responsiveness, eating in the absence of hunger, reinforcing value of food and capacity to voluntarily inhibit eating [305]. More recently, intuitive eating (an adaptive form of eating behaviour essentially based on hunger and satiety cues to regulate food intake) [306] has also received attention.

The obesogenic environment, which is characterised by plentiful, palatable, energy dense, easily accessible, inexpensive foods served in large portions [9, 10, 12, 58, 67], has the potential to interact with an individual's eating behaviour to influence resistance or susceptibility to obesity. For example: an individual who is hyper-responsive to food cues is more likely to eat more frequently, and have low control over eating cessation. Therefore such an individual ingests large meals and has an increased susceptibility to gaining weight in an environment with high availability of palatable foods and large portion sizes [305].

Researchers have developed various laboratory measures and psychometric (self-report) questionnaires to capture information about eating behaviours. Laboratory measures consist of direct observations of behaviour under controlled conditions and include: the examination of food choice and food preference, different eating situations, multiple meals, snacking behaviour and social and environmental influences (eg eating watching television and eating while in contact with other people) [117, 307]. Psychometric questionnaires are a cost-effective, relatively quick technique used in large-scale research projects to gather information on eating behaviour traits [117, 305]. Two such questionnaires that have been used widely to assess eating behaviour in adults are the Three Factor Eating Questionnaire (TFEQ) [308] and the Dutch Eating Behaviour Questionnaire (DEBQ) [309]. The TFEQ is designed to measure three distinct constructs of eating behaviour – restrained eating, disinhibition and hunger; while the DEBQ assesses restrained eating, emotional eating and external eating. The more recently developed Intuitive Eating Scale (IES) [310] and the updated version, Intuitive
Eating Scale-2 (IES-2) [311], are psychometric questionnaires designed to assess intuitive eating.

As with previous topics in this review, for the sake of brevity the following sections (2.5.5.1.1 to 2.5.5.1.7) have been limited to describing the eating behaviour constructs that have been assessed to date in the obesity resistance literature and in data collection for this thesis. A comprehensive description of other constructs of eating behaviour can be found in recent reviews on the topic [117, 305].

2.5.5.1 Selected Constructs of Eating Behaviour

2.5.5.1.1 Restrained Eating

As previously described, restrained eating (or dietary restraint) is an eating behaviour construct that can be assessed by both the TFEQ and the DEBQ. Dietary restraint has been described as the ‘cognitively mediated effort to combat the urge to eat’ [312]. Some degree of self-monitoring and cognitive control over the food that is eaten seems a prudent adaptive response to the abundant, palatable and energy dense food supply of the obesogenic environment if weight gain is to be avoided [313]. However, the suggestion that an individual should monitor and control their food intake has been contentious.

‘Restraint theory’ [314], which developed in the 1970s, initially dominated the clinical literature on eating behaviour and weight control. This theory proposes that dietary restraint (cognitive control) reduces sensitivity to internal satiety cues (physiological control), resulting in disinhibition or overeating [315]. Thus rendering dietary restraint as ineffective or counterproductive in terms of weight control. In a recent review investigating dietary restraint and self-regulation in eating behaviour, Johnson and colleagues [313] concluded that although overeating may often accompany dietary restraint, evidence from epidemiological studies and field-based interventions provide little support for the proposal that restrained eating leads to increased disinhibition. In fact, the evidence suggests that responsibility for the co-occurrence of these seemingly opposing eating
behaviours may lie more with disinhibition (and the resulting weight gain) causing dietary restraint, rather than the other way around [313].

As might be expected, there is evidence that dieting and restrained eating overlap to some extent [316]. However, restrained eaters are not necessarily dieters, as both dieting and restrained eating represent distinct concepts that relate differently to eating behaviour [317]. It appears most normal weight restrained eaters restrict their eating to prevent weight gain rather than to lose weight [318] and as a group in fact do not restrict their intake enough to lose weight [319-321]. By comparison, the goal of dieters is presumably to restrict energy intake sufficiently to lose weight [317]. Consequently, compared to dieting, restrained eating is associated with positive eating behaviours and weight control, whereas dieting is more closely associated with disinhibition [322-324].

If, as it appears, the concern over a cognitively controlled eating style is unfounded in terms of promoting overeating, then dietary restraint has the potential to contribute to effective weight control. Longitudinal studies have shown that increases in dietary restraint over time are associated with greater weight loss [322, 325-327]. In addition, individuals who have successfully maintained weight loss report high levels of restraint combined with low levels of disinhibition [328-330].

2.5.5.1.2 Disinhibition

Although dietary restraint received much of the initial focus in the literature in relation to weight control, the development and widespread use of the TFEQ [308] has seen the construct of disinhibition gradually gain more attention [331]. Disinhibition indicates a tendency to over-eat and eat opportunistically eg eating when others are eating, eating in response to positive and negative emotional states and being responsive to the palatability of food [305, 332, 333]. It has been suggested that disinhibition (as measured by the TFEQ subscale) may be closely linked to food sensitivity and/or factors that influence the initiation of eating and also to weak satiety processes or weaker cognitive or motivational controls associated with a failure to inhibit eating once started [305].
Results of numerous multi-country, prospective and cross-sectional studies show a consistent positive association between BMI or weight gain and disinhibition scores [305]. This positive association has been seen across different socioeconomic gradients [334], in individuals of differing dieting status [335] and in individuals with varying weight histories [328]. Along with being consistently associated with a higher BMI, disinhibition has also been consistently associated with higher energy intakes [328, 334, 336] and other mediating variables, such as less healthful food choices, which may contribute to overweight and obesity [331].

It is likely that disinhibition does not act in isolation, but may exert its effect in combination with the level of dietary restraint and hunger (the other TFEQ factors). For example a higher BMI is observed when a high disinhibition score is combined with a high hunger score [334, 336, 337]. Similarly, individuals who score high for disinhibition and low for dietary restraint have a higher BW and BMI, whereas those who express low disinhibition and high restraint have a much lower BW [334, 338, 339]. The combination of high disinhibition and low dietary restraint has also been associated with a higher susceptibility to weight gain and higher sedentary behaviour [333].

2.5.5.1.3 Hunger
Hunger is the third eating behaviour construct measured by the TFEQ. The factor of hunger relates to an individual’s perception of their level of motivation to eat and the extent to which this evokes food intake [331, 332]. Theoretically, individuals who report high levels of hunger would be more susceptible to overeating compared to those who do not report being hungry often [307]. This supposition is supported by a number of studies where positive associations have been observed between susceptibility to hunger and energy intake [307, 336, 340, 341]. In addition, obese subjects generally display higher scores for susceptibility to hunger than non-obese individuals [307, 336, 337, 340, 342].

As discussed in the previous section (2.5.5.1.2), the eating behaviour constructs do not necessarily operate in isolation but rather in combination. Successful weight loss has been associated with decreases in hunger and disinhibition and an
increase in dietary restraint [326, 343-347]. While low hunger and disinhibition and high dietary restraint have been associated with successful weight maintenance following weight loss [264, 337, 348-351].

2.5.5.1.4 Emotional Eating
Along with dietary restraint and external eating, emotional eating is one of the constructs of eating behaviour that is assessed using the DEBQ [309]. Emotional eating refers to the tendency to overeat in response to negative emotions (such as depression, stress, anxiety etc) as a result of poor interoceptive awareness [352]. It would therefore be expected that high scorers on emotional eating scales would increase their food intake in response to the experience of negative emotions. Accordingly, high emotional eaters have been shown to consume significantly more sweet, high-fat foods and more energy dense foods in response to stress than low emotional eaters [353-355]. Further, results from prospective studies indicate that individuals with high scores for emotional eating appear to be at increased risk for becoming overweight/obese, because overconsumption seems to be more strongly related to weight gain in people with high degrees of emotional eating [352, 356-358]. Additionally there is some evidence from controlled laboratory experiments that positive emotions can also induce overeating in participants scoring high on an emotional eating scale [359].

The relationship between emotions and eating behaviour is complex and not always clear [360, 361]. Recently a new model has been proposed in an attempt to better encompass and describe this complex relationship. Macht (2008) identified five classes of emotion-induced changes in eating:

1. Emotional control of food choice
2. Emotional suppression of food intake
3. Impairment of cognitive eating controls
4. Eating to regulate emotions
5. Emotion-congruent modulation of eating
These emotion-induced changes in eating can be a result of interference of eating by emotions, a by-product of emotions, and a consequence of regulatory processes (emotions may regulate eating, and eating may regulate emotions) [362].

Not only do there appear to be different facets of emotional eating, but Singh (2014) also proposes the existence of a bi-directional relationship between mood, food and obesity. As previously described, various emotions influence food intake and mood states can trigger eating of palatable foods for comfort in a negative emotional state. This repetitive eating of energy dense, sweet, high-fat comfort foods, has the potential to lead to overweight/obesity. Obesity in turn impacts on mood for example, due to the associated co-morbidities of depression and anxiety [363-365]. These negative emotions then act as a trigger to consume palatable foods for comfort and a vicious cycle ensues. Recent results from cross-sectional [366-368] and prospective research [369] support the role of emotional eating acting as a mediator between depression and obesity.

2.5.5.1.5 External Eating
External eating is overeating in response to external food-related stimuli such as sight, smell and taste of attractive food regardless of internal feelings of hunger and satiety [369]. It is derived from Schacter’s externality theory of obesity [370], which postulates that external eaters are relatively insensitive to internal physiological hunger and satiety signals and show an elevated responsiveness to food-related cues in the immediate environment. Consequently, the potential exists for external eaters to overeat and increase the risk of overweight/obesity compared to individuals who score low on the external eating scale [309].

To date, various cross-sectional studies have observed no difference between overweight and normal weight people in their degree of external eating as assessed by the DEBQ [357, 371-375]. In addition, there is accumulating evidence from prospective studies that external eating may not be a good predictor of BMI change [352, 356, 358].
This absence of a difference between overweight and normal BW individuals in their degree of external eating seems surprising especially in the context of an obesogenic environment that is characterised by widespread availability of highly palatable food (ie external food cues). Herman and Polivy (2008) propose that there are two types of external eating cues (normative and sensory) and that these cues affect eaters differently. According to this model, normative external eating cues refer to environmental indicators of how much one should eat eg portion size; whereas sensory cues refer to properties of the food itself that make one more (or less) likely to eat it eg palatability (see [376] for a detailed description of these paradigmatic examples). These researchers contend that normative cues are universal, affecting all eaters indiscriminately, whereas sensory cues have a much stronger effect in certain people, namely the obese, dieters and hungry individuals [376]. At this time, however, the tools designed to measure external eating are unable to assess this distinction between normative and sensory cues.

2.5.5.1.6 Intuitive Eating
Intuitive eating is an adaptive eating style based on physiological hunger and satiety cues rather than situational and emotional cues to regulate food intake [310, 377]. This form of eating was initially described by Tribole and Resch (1995), and the central features operationalised into the IES, developed by Tylka in 2006 [310] and revised in 2013 [311], to measure the components of intuitive eating.

Initially three core components of intuitive eating were identified and form the subscales of the IES [310]:

1) Unconditional Permission to Eat (When Hungry and What Food is Desired)
   This component reflects a readiness to respond to internal hunger and an avoidance of classifying foods as acceptable (‘good’) or unacceptable (‘forbidden’).

2) Eating for Physical Rather Than Emotional Reasons
   This component reflects eating to satisfy physical hunger rather than to cope with emotional distress.

3) Reliance on Hunger and Satiety Cues
This component reflects an awareness of, and trust in physiological hunger and satiety cues to guide eating behaviour.

Recently, Tylka and Kroon Van Diest [311] developed a revised version of the scale (IES-2) and identified a fourth component:

4) Body-Food Choice Congruence

This component reflects choosing foods that meet both physical (body functioning) and sensory (taste/flavour) needs.

Evidence presented in a number of reviews indicates that intuitive eating is associated with positive health and wellbeing outcomes [377-381]. Specifically, eating intuitively has been associated with increased self-esteem and decreased body dissatisfaction [378], less disordered eating, a better body image and greater emotional functioning [380, 381]. With respect to weight control, cross-sectional survey studies indicate that intuitive eaters have a lower BMI than non-intuitive eaters [377, 379, 382]. However, evidence from clinical studies suggests that implementation of an intuitive eating programme does not result in weight reduction but likely assists with weight maintenance, and this may linked to the length of follow-up and completion rates of programmes [379].

There are a number of limitations in the literature examining intuitive eating including: small sample sizes, homogenous participant groups (the majority of studies have included mainly Caucasian female participants), short follow-up periods, inconsistent comparison groups (eg traditional weight-loss groups or alternative non-dieting approaches or wait-list control groups) and no or limited information regarding programme adherence and completion rates. Therefore, the findings may not necessarily be generalisable to more diverse populations (eg males, other non-Caucasian ethnic groups), as well as there being some uncertainty regarding the long-term effects of intuitive eating interventions.

2.5.5.1.7 Eating Frequency

Increased eating frequency has been proposed to have a positive impact on weight control via two potential mechanisms: i) an increase in energy expenditure due to
an increase in the thermic effect of food; and ii) a decrease in energy intake due to improvement in appetite control (decreased hunger and increased satiety) [383-385]. However, in the current obesogenic environment, eating more frequently may have a detrimental effect on weight control. The total energy intake of an individual is determined by the number of ingestion occasions (including both food and beverages), and the energy consumed per occasion [386]. Therefore, eating more frequently in the current food environment may actually lead to increased exposure to large portion sizes of energy dense foods, resulting in excess energy intake and the potential for weight gain [385, 387].

Results from epidemiological studies investigating the relationship between eating frequency and measures of adiposity have been mixed, with some showing an inverse relationship [388-391], others no association [392-396], while others have reported a positive association [397-401]. There are a number of methodological factors that may be responsible for this inconsistency, including the limited use of dietary assessment methods to provide information on actual dietary habits; the absence of, or unsatisfactory adjustment for potential confounding factors such as underreporting of energy intake and PA levels; the heterogeneous populations within the same study (including both healthy normal weight and overweight/obese subjects); and lack of consensus regarding the definition of what constitutes an eating occasion [384, 387, 401, 402].

An eating occasion has been variously defined as a neutral term encompassing both meals and snacks that can be identified by the participant [395, 403, 404] or by the time of day in which the eating occasion occurs [405, 406]. Some definitions include a time interval (e.g. 15, 30, 45 and 60 min) to separate one eating occasion from another [407-409], whereas more recently, a definition that includes a minimum energy content of 210 kJ (50 kcal) in addition to a time interval has been adopted by a number of researchers [390, 400, 409, 410]. A recent study compared different definitions of eating occasion with the characterisation of eating patterns in nationally representative data from Australian adults [411]. The results of this study indicated that the 15 min time interval plus 210 kJ energy
The definition was the best method for predicting variance in total energy intake and total amount of food/beverage consumed.

The effectiveness of manipulation of eating frequency and weight control has been the subject of a number of recent reviews. Kant (2014) observed a consistently null finding for the manipulation of eating frequency to promote weight loss in adults from randomised controlled trials ranging in length from 1 week to 1 year. In addition, in those trials where energy intake was reported, higher eating frequency was not accompanied by lower energy intakes [387]. Kulovitz and colleagues [384] reviewed trials investigating the impact of eating frequency manipulation of BW or composition changes in overweight/obese individuals during hypocaloric weight loss interventions. From the limited amount of literature available, these researchers concluded that manipulating eating frequency does not appear to have a significant role in body composition changes or weight reduction during controlled feeding trials in overweight/obese adults [384]. The review conducted by Leidy and Campbell [385] focused on studies investigating the effect of eating frequency manipulation on measures of appetite control. Using the 3 meals per day pattern as the reference, Leidy and Campbell [385] concluded that increased eating frequency (>3 eating occasions.d⁻¹) has minimal, if any impact on appetite control and food intake, whereas decreased eating frequency (<3 eating occasions.d⁻¹) has a negative impact on appetite control.

In an attempt to overcome the frequent lack of statistical power due to small sample sizes that are common in the randomised controlled trials in this area, Schoenfeld and colleagues [383] conducted a meta-analysis of studies investigating the effect of meal frequency on body composition and weight loss. The initial analysis suggested feeding frequency was positively associated with decreases in fat mass and %BF and increases in FFM. However, sensitivity analysis of the data indicated the positive findings were attributed to the results of a single study. The reviewers therefore suggest treating these results with circumspection and, additionally, given the small difference in magnitude of effect between eating
frequencies, any potential differences, if they exist at all, are limited in their practical significance [383].

2.5.5.2 Studies Investigating Eating Behaviour in Obesity Resistant (ORI) and Obesity Susceptible Individuals (OSI)

Assessment of eating behaviour in ORI compared to OSI has been undertaken in a small number of studies using, in most cases the TFEQ [31-34], but also the DEBQ [25]. Participants in the study conducted by Germain and colleagues [25] completed the DEBQ as part of baseline measurement procedures. Constitutionally thin individuals (CTI), used to represent individuals resistant to obesity, reported lower restrained eating (mean ± SEM) than normal BMI age-matched controls (12.9 ± 18 vs 26.3 ± 2.7, P=0.01). Results for the emotional eating and external eating subscales were not reported.

The TFEQ was used to assess eating behaviour in thin versus reduced obese individuals in two studies conducted by Cornier and colleagues [31, 32]. In the more recent study, restrained eating was reported to be less in thin compared to reduced obese participants [32], while no difference was observed in the earlier study [31]. However, both studies reported similar findings for disinhibition (lower in thin compared to reduced obese) and hunger (no differences between the study groups).

More consistent results were seen in the two studies where obesity resistant and obesity prone individuals were defined based on a combination of current BMI, weight history, BMI of first degree relatives and self-identification. All three subscales of the TFEQ (restrained eating, disinhibition and hunger) were reported to be lower in ORI compared to obesity prone individuals [33, 34]. To the candidates knowledge there are no studies to date that have made an attempt to assess intuitive eating or eating frequency in ORI compared to OSI.

2.5.5.2.1 Summary

Results from the limited number of studies comparing individuals resistant to obesity (including CTI and thin) compared to individuals susceptible to obesity
(obesity prone and reduced obese) indicate that eating behaviour is potentially different between these two groups. Specifically it appears levels of restrained eating and disinhibition are lower in ORI compared to OSI, while the findings for hunger are less clear. It is worthwhile to note that the studies reviewed above, in which the TFEQ has been used to assess eating behaviour, have all been conducted by researchers working out of the Colorado School of Medicine.

2.5.6 Responses to Energy Manipulation

An energy imbalance, caused by increased energy intake or decreased energy expenditure or a combination of the two, is the unfortunate potential product of living in an obesogenic environment. How an individual responds (overtly or covertly) over time to this potential imbalance has implications in terms of weight maintenance.

Analysis of overfeeding experiments show that weight gain is often less than expected based on the magnitude of the energy manipulation [412-414]. In addition there appears to be large inter-individual variation in weight gain during standardised controlled overfeeding. This was clearly demonstrated in the seminal ‘experimental obesity’ work conducted by Sims and colleagues in the Vermont Prison Overfeeding Study [415-417]. Despite similar levels of PA, individuals differed markedly in their ability to gain weight, with some achieving the goal of 25% weight gain with ease compared to others who gained weight gradually and could not achieve the goal despite consuming considerably more calories. Subsequently, large inter-individual variation in weight gain in response to overfeeding was apparent in all 16 studies selected for inclusion in a systematic review conducted by Joosten and Westerterp (2006).

More recently, an intriguing study conducted by the Swedish Fast Food Study Group also showed large variation in the way young healthy BW (mean BMI = 21.9 kg.m⁻²) males and females responded to an intervention designed to increase BW by 5-15% over 4 weeks [418, 419]. Eighteen participants were asked to double their daily caloric consumption by eating at least 2 fast food based meals a day and to not exceed 5000 steps per day. One participant achieved a 15% gain in BW after
just 2 weeks; four participants reached the 15% increase in BW by the end of 4 weeks; 12 participants achieved a BW increase of >5% but less than 15%; and one participant only achieved an increase of 3.3% in BW [418]. This wide inter-individual variation in weight gain during overfeeding that is often less than predicted suggests there may be differences in the capacity of some individuals to regulate energy expenditure and therefore metabolic efficiency, potentially predisposing or protecting against obesity [414].

A less than expected weight gain in response to overfeeding can be partly explained by an obligatory increase in energy expenditure due to increased BW and changes in body composition [420] and the larger amount of food that needs to be digested and absorbed [414]. More recently developed models to predict weight change take into consideration these metabolic adaptations that occur during weight change [413]. However, the large inter-individual variation in weight gain, despite the same level of overfeeding, suggests some individuals may have the ability to regulate their energy expenditure beyond the associated obligatory costs of weight gain – potentially resisting weight gain [412]. Changes in energy expenditure above the obligatory costs of weight gain are considered adaptive thermogenesis [412, 414].

The evidence for adaptive thermogenesis as a mechanism to resist weight gain remains inconsistent for a number of reasons:

1) It is difficult to accurately assess all the components of total energy expenditure (BMR, diet-induced energy expenditure, AEE, and non-exercise activity thermogenesis).

2) The magnitude of change in total energy expenditure above the obligatory costs of weight gain is likely to be small and therefore difficult to quantify considering measurement errors, errors in assumptions made and small (day to day) differences in PA.

3) It is unclear in which component or components of total energy expenditure adaptive changes can occur and whether components can overlap due to measurement limitations.
4) It is difficult to pool results from different overfeeding studies due to the use of markedly different macronutrient compositions, measurement techniques and study length.

5) The length of study period may be too short to assess adaptive thermogenesis, which is involved in long-term energy balance regulation.

6) Overfeeding studies are designed to result in weight gain, which inherently limits the number of overweight and obese subjects willing to participate and therefore the ability to assess if obesity prone individuals have a reduced capacity for adaptive thermogenesis.

[412, 421, 422]

In response to this final issue it would therefore be of interest to assess the response to overfeeding in individuals who appear resistant to obesity compared to those who display obesity susceptibility. This may help provide further evidence of the existence (or not) of adaptive thermogenesis and it's potential protective role against weight gain.

2.5.6.1 Studies Investigating Responses to Energy Manipulation in Obesity Resistant (ORI) and Obesity Susceptible Individuals (OSI)

A number of studies within the obesity resistance literature have attempted to investigate the response of ORI versus OSI to energy manipulation (over- and/or under-feeding). Two of these studies, in which obesity resistant and obesity prone participants were compared, focused solely on the effect of short-term over- and under-feeding on neuronal responses to visual food cues [79] and sweet taste [33] and therefore fall outside the scope of this literature review. A full description of the studies relevant to this section is presented in Table 2.3.

Several variables have been assessed in the context of energy manipulation within the obesity resistance literature including body composition [25], hormone levels [25, 26], energy balance [25, 80], substrate oxidation [80], appetite responses [31, 32, 34], PA [82] and insulin and glucose metabolism [30].
<table>
<thead>
<tr>
<th>Author(s)</th>
<th>Study Aim</th>
<th>Design</th>
<th>Classification of Groups</th>
<th>Participant Characteristics</th>
<th>Feeding Intervention</th>
<th>Variables of Interest</th>
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<tbody>
<tr>
<td>Germain et al [25]</td>
<td>To evaluate appetite regulatory hormones in constitutionally thin individuals in an inverse paradigm of diet-induced weight loss.</td>
<td>Parallel CT (Constitutionally Thin): N=8 mean BMI = 17.1 kg.m⁻² Controls: N=8 mean BMI = 22.1 kg.m⁻²</td>
<td>Stable body weight throughout post-pubertal period</td>
<td>No amenorrhoea, no eating disorders, no markers of undernutrition including normal IGF-1, oestradiol, free triiodothyronine, cortisol, non-blunted leptin, no hepatic disorders, no over-exercising behaviours according to MOSPA-Q, no out-patient consultation regarding body weight gain</td>
<td>4 wk fat overfeeding (2640 kJ.d⁻¹) Free-living, Maintain normal lifestyle (diet and physical activity) Provided with packages containing a fixed daily quantity of olive oil, peanuts, gruyere cheese and butter</td>
<td>Energy Balance:</td>
<td>Change in Body Weight: CT &lt; Controls (baseline 19.4 ± 1.5 vs. 17.9 ± 1.5, P=0.003; CT vs. Controls 17.9 ± 1.5 ± 1.5 vs. 17.9 ± 1.5 ± 1.5 kg, P=0.026)</td>
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<td>Thomas et al [26] To investigate hormonal and metabolic responses to short-term overfeeding and underfeeding in individuals recruited as obese-resistant (OR) or obese prone (OP)</td>
<td>OR (Obesity Resistant): BMI 17-25 kg.m(^{-2}) • responded to advertisements for ‘naturally thin people’ • self-defined as ‘constitutionally thin’ based on their perception of difficulty gaining weight, expending little effort to maintain weight and sense of body weight regulation that was different to others • no obese first degree relatives • never overweight • weight stable despite few to no attempts to lose weight • no high levels of physical activity</td>
<td>OR N=29 (14 F, 15 M) mean BMI = 20.9 kg.m(^{-2})</td>
<td>EU: based on estimated energy requirements OF: 40% energy over EU UF: 40% energy under EU All diets 50%TEI CHO, 30%TEI fat, 20%TEI protein</td>
<td>Hormone Levels AUC leptin, insulin, ghrelin, PYY, GLP-1, and glucose AUC (mean ± SD)</td>
<td>Leptin (AUC): OR &lt; OP with EU, OF and UF (EU: 598 ± 71 vs 1881 ± 72 ng.ml(^{-1}), P&lt;0.001) (OF: 789 ± 67 vs 2362 ± 75 ng.ml(^{-1}), p&lt;0.001) (UF: 526 ± 69 vs 1826 ± 72 ng.ml(^{-1}), P&lt;0.001)</td>
<td>Insulin (AUC): OR &lt; OP with EU and OF (EU: 6908 ± 452 vs 9147 ± 436 ng.ml(^{-1}), P&lt;0.05) (OF: 8899 ± 428 vs 10956 ± 448 ng.ml(^{-1}); P&lt;0.05) NS differences with UF Ghrelin AUC: OR &gt; OP with EU and UF (EU: 14725 ± 2286 vs 124586 ± 2207 pg.ml(^{-1}), P&lt;0.05) (UF: 154776 ± 2226 vs 130877 ± 2207 pg.ml(^{-1}), P&lt;0.05) PYY, GLP-1, and Glucose (AUC): NS differences with EU, OF or UF</td>
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<td>OP (Obesity Prone) • BMI 20-30 kg.m(^{-2}) • responded to advertisements for ‘people who struggle with their weight’ • self-defined as chronically struggling with weight control • ≥ 1 obese first degree relative • history of weight fluctuations despite</td>
<td>OP N=29 (15 F, 14 M) mean BMI = 26.1 kg.m(^{-2}) All healthy adults Age 25-35 y No significant medical or psychiatric disease (including depression and eating disorders) Matched for age (± 2 y), sex and ethnicity/race</td>
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<td>Schmidt et al [80]</td>
<td>OR (Obesity Resistant)</td>
<td>OR N=30 (14 F, 16 M) mean BMI: F = 19.6; M = 21.7 kg.m⁻²</td>
<td>EU: based on estimated energy requirements OF: 1.4 x energy over EU Both diets 46%TEI CHO, 34%TEI fat, 20%TEI protein</td>
<td>Energy Expenditure: TEE assessed for 24 h in whole-room calorimeter (mean ± SE)</td>
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<td>OP (Obesity Prone)</td>
<td>OP N=22 (14 F, 8 M) mean BMI: F = 22.7; M = 24.8 M kg.m⁻²</td>
<td>Day 1-4: EU Day 5-7: EU or OF Day 7: 24 h in whole-room calorimeter All food and beverages supplied Study phases separated by ≥1 mo</td>
<td>Substrate Oxidation: CHO &amp; fat calculated from RER and oxygen consumption Protein estimated by urinary urea nitrogen excretion (mean ± SE)</td>
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<td>Same group classification as Thomas et al (2014)</td>
<td>• matched to OR for age, FFM and RMR</td>
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<td>TEE: OR – increased with OF (2283 ± 58 to 2393 ± 44 kcal.d⁻¹, P&lt;0.05) OP – increased with OF (2372 ± 66 to 2482 ± 51 kcal.d⁻¹, P&lt;0.01) OR vs OP – NS difference with EU or OF</td>
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<td>Same group classification as Thomas et al (2014)</td>
<td>• matched to OR for age, FFM and RMR</td>
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<td>Substrate Oxidation: no differences between OR and OP on either EU or OF (P&gt;0.05); both increased CHO and protein and decreased fat oxidation on OF cf EU</td>
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<td>Randomised Cross-over 2-arm</td>
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<td>All non-obese Age 25-35 y No significant medical illnesses or medications that affect weight or lipid metabolism No eating disorders</td>
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<td>CHO oxidation: OR – increased with OF (968.9 ± 91.4 to 1239.9 ± 74.0 kcal.d⁻¹, P&lt;0.01) OP – increased with OF (1017.9 ± 79.7 to 1394.1 ± 100.0 kcal.d⁻¹, P&lt;0.01) OR vs OP – NS differences with EU or OF</td>
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<td>Fat oxidation: OR – decreased with OF (898.3 ± 100.9 to 674.8 ± 71.7 kcal.d⁻¹, P=0.02) OP – decreased with OF (911.3 ± 88.2 to 650.2 ± 81.2 kcal.d⁻¹, P=0.01) OR vs OP – NS differences with EU or OF</td>
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<td>Protein oxidation: OR – increased with OF (467.3 ± 20.8 to 544.5 ± 22.7 kcal.d⁻¹, P&lt;0.01) OP – increased with OF (423.7 ± 22.7 to 527.4 ± 26.3 kcal.d⁻¹, P&lt;0.001) OR vs OP – NS differences with EU or OF</td>
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<td>Thomas et al [34]</td>
<td>OR (Obesity Resistant) Same group classification as Thomas et al (2014)</td>
<td>OR (Obesity Resistant) Same cohort as Thomas et al (2014) OR N=29 (14 F, 15 M) mean BMI = 20.9 kg.m⁻²</td>
<td>Same feeding intervention as Thomas et al (2014) EU: based on estimated energy requirements OF: 40% energy over EU UF: 40% energy under EU All diets 50%TEI CHO, 30%TEI fat, 20%TEI protein</td>
<td>Appetite Responses Hunger, prospective food consumption and satiety VAS at 0, 30, 60, 90, 120, 150, 180 AUC (mean ± SEM) iAUC</td>
<td>Hunger (fasting): (data in figure) OR and OP – decreased with OF (P&lt;0.05) OR and OP – NS difference with UF OR vs OP – NS differences with OF or UF Hunger (AUC): OR and OP – decreased with OF (P&lt;0.05) OR and OP – increased with UF (P&lt;0.05) (OR: EU = 8104 ± 494; OF = 5515 ± 481; UF = 9801 ± 481 mm x 180 min) (OP: EU = 8656 ± 494; OF = 6250 ± 481; UF = 10593 ± 481 mm x 180 min) OR vs OP – NS differences with OF or UF Hunger (iAUC): OR and OP – NS differences with OF or UF OR vs OP – NS differences with OF or UF Prospective Food Consumption (fasting): (data in figure) OR and OP – decreased with OF (P&lt;0.05) OR and OP – NS difference with UF OR vs OP – NS differences with OF or UF Prospective Food Consumption (AUC): OR and OP – decreased with OF (P&lt;0.05) OR – NS difference with UF OP – increased with UF (P&lt;0.05) (OR: EU = 10344 ± 474; OF = 6554 ± 462; UF = 11335 ± 462 mm x 180 min) (OP: EU = 9318 ± 474; OF = 7187 ± 474; UF = 11098 ± 462 mm x 180 min) OR vs OP – NS differences with OF or UF Prospective Food Consumption (iAUC): OR and OP – NS differences with OF or UF OR vs OP – NS differences with OF or UF Satiety (fasting): (data in figure) OR and OP – increased with OF (P&lt;0.05) OR and OP – decreased with UF OR vs OP – NS differences with OF or UF</td>
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<td>Author (y) Study Aim Design</td>
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<td>Schmidt et al [82] To determine if spontaneous physical activity responds differently to short-term overfeeding in obesity prone versus obesity resistant humans. Randomised Cross-over 2-arm</td>
<td>OR (obesity resistant) Same group classification as Thomas et al (2014)  • BMI 16.9 – 25.5 kg.m⁻²  OP (obesity prone) Same group classification as Thomas et al (2014)  • BMI 19.6 – 30.6 kg.m⁻²  • matched to OR for age and RMR</td>
<td>OR  N=32 (16F, 16 M) mean BMI = 20.6 kg.m⁻²  OP  N=23 (15 F, 8 M) mean BMI = 23.8 kg.m⁻²  All healthy adults  Age 25-35 y  No significant medical illness or medications that affect weight of lipid metabolism  No psychological dysfunction or eating disorders</td>
<td>EU: based on estimated energy requirements  OF: 1.4 x energy over EU  Both diets 50%TEI CHO, 30%TEI fat, 20%TEI protein  Day 1-4: EU  Day 5-7: EU or OF  Day 7: 23 h in whole-room calorimeter  Day 8-10: ad libitum diet (provided with 25% more energy than EU and advised to ‘eat as much as you want’  All food supplied  Study phases separated by ≥1 mo</td>
<td><strong>Satiety (AUC):</strong>  OR and OP increased with OF (P&lt;0.05)  OR and OP decreased with UF (P&lt;0.05)  (OR: EU = 8109 ± 481; OF = 10113 ± 468; UF = 6460 ± 468 mm x 80 min)  (OP: EU = 8469 ± 481; OF = 10484 ± 481; UF = 6264 ± 468 mm x 180 min)  OR vs OP – NS differences with OF or UF  <strong>Satiety (iAUC):</strong>  OR and OP – NS differences with OF or UF  OR vs OP – NS differences with OF or UF</td>
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<td><strong>Spontaneous Physical Activity (SPA):</strong> Assessed day 5-10 by PAMS (physical activity monitoring system) consisting of paired inclinometers and accelerometers worn on both sides of the upper and lower body (mean ± SD)</td>
<td><strong>SPA:</strong>  OR vs OP – NS differences when examined across all study periods  Except day 10 (3rd day of ad libitum diet):  OR – maintained time spent walking (+0.2%, P&gt;0.05)  OP – decreased time spent walking (-2.0% of time, P=0.03)</td>
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<td><strong>Steps per day:</strong>  OR vs OP – NS differences in average number of steps per day over the duration of the study  (8017 ± 441 vs 7967 ± 560 steps.d⁻¹, P=0.05)  Except day 10 (3rd day of ad libitum diet):  OR &gt; OP (9240 ± 728 vs 7622 ± 932, P&lt;0.05)</td>
<td><strong>Physical Activity:</strong>  Pedometer day 5-10 (Digi-Walker) measured steps per day (mean ± SD)</td>
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<td>Cornier et al [32]</td>
<td>To examine the effects of short-term overfeeding on the neuronal response to food-related visual stimuli in individuals prone and resistant to weight gain.</td>
<td>Thin</td>
<td>Thin N=22 (10 F, 12 M) mean BMI = 21.6 kg.m⁻²</td>
<td>EU: based on estimated energy requirements OF: 30% energy over EU Both diets 50%TEI CHO, 30%TEI fat, 20%TEI protein</td>
<td>Appetite Responses VAS before and after each meal day 4-5</td>
<td>Hunger: Thin and RO – decreased with OF (78.8 ± 2.2 to 71.2 ± 2.5 mm, P=0.009) Thin vs RO – NS differences with OF Prospective Meal Consumption: Thin and RO – decreased with OF (79.3 ± 2.2 to 71.0 ± 2.4 mm, P=0.003) Thin vs RO – NS differences with OF Satiety: Thin and RO – increased with OF (75.1 ± 2.9 to 82.3 ± 1.8, P=0.01) Thin vs RO – NS differences with OF</td>
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<td>Randomised Crossover 2-arm</td>
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<td>RO (Reduced Obese)</td>
<td>RO N=19 (10 F, 9 M) mean BMI = 27.4 kg.m⁻²</td>
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<td>• 8-10% body weight loss in a supervised weight loss programme • maintained new reduced weight for 8 wk prior to study entry</td>
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<td>Cornier et al [30]</td>
<td>To examine the effects of 3 days of overfeeding on insulin action and glucose kinetics in lean and reduced-obese (RO) individuals.</td>
<td>Lean</td>
<td>Lean 13 (7 F, 6 M) mean BMI: F = 20.6 ± 1.8; M = 21.3 ± 3.0 kg.m⁻²</td>
<td>EU: based on estimated energy requirements OF: 50% energy over EU Both diets 50%TEI CHO, 30%TEI fat, 20%TEI protein</td>
<td>Insulin Action &amp; Glucose Kinetics: Assessed by euglycaemic hyperinsulinaemic clamp (mean ± SEM)</td>
<td>Insulin-suppressed Glucose Production: Lean F – decreased with OF (EU: 1.92 ± 0.36 to 0.36 ± 0.16; OF: 2.13 ± 0.17 to 0.86 ± 0.12 mg.kg⁻¹.min⁻¹, P=0.04) Lean M, RO F and RO M – NS differences with OF Insulin-stimulated Glucose Disposal: Lean F, Lean M, RO F and RO M – NS differences with OF</td>
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<td>Parallel</td>
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<td>RO (Reduced Obese)</td>
<td>RO 9 (5 F, 4 M) mean BMI: F = 30.4 ± 2.6; M = 27.5 ± 1.8 kg.m⁻²</td>
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<td>• Initial BMI 30-35 kg.m⁻² • ≥ 10% weight loss in supervised weight loss programme • weight loss maintained to within 2% throughout study</td>
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<td>Cornier et al [31] To test the hypothesis that thin individuals, who appear to be resistant to weight gain in an obesogenic environment, would better sense excessive caloric intake with appropriate changes in measures of hunger, satiety, palatability, and ad libitum intake than reduced-obese individuals, who are at high risk for weight gain.</td>
<td>Thin</td>
<td>Thin 13 (7F, 6 M) mean BMI: F = 20.6; M = 21.3 kg.m⁻²</td>
<td>EU: based on estimated energy requirements OF: 50% energy over EU Both diets 50%TEI CHO, 30%TEI fat, 20%TEI protein</td>
<td>Appetite Responses: VAS before and after meals on day 6-7 of EU and day 8-10 OF (mean ± SEM)</td>
<td>Hunger: Thin – decreased with OF (68 ± 6 to 41 ± 6 mm; P&lt;0.0001) RO – NS difference with OF (63 ± 6 to 65 ± 7 mm; P=0.67) Satiety: Thin and RO – increased with OF (Thin: 6 ± 4 to 88 ± 4 mm, P&lt;0.0001) (RO: 72 ± 5 to 80 ± 5 mm, P=0.04) Greater increase in Thin vs RO (35 vs 11%; P=0.0016) Thirst: Thin and RO – NS difference with OF Nausea: Thin and RO – NS difference with OF</td>
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<td>• BMI &lt; 23 kg.m⁻²</td>
<td>Thin 13 (7F, 6 M) mean BMI: F = 20.6; M = 21.3 kg.m⁻²</td>
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<td>RO (Reduced Obese)</td>
<td>RO 9 (5 F, 4 M) mean BMI: F = 30.4; M = 27.5 kg.m⁻²</td>
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<td>• Initial BMI 30-35 kg.m⁻²</td>
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<td>• 8-10% weight loss in supervised weight loss programme</td>
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<td>• maintained weight loss for ≥ 4 wk prior to study entry</td>
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<td>Thin</td>
<td>All healthy Aged 25-45 y No metabolic or psychiatric disease including eating disorders</td>
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Cornier and colleagues [30] investigated the effects of 3 days of overfeeding (1.5 times estimated energy requirements) on insulin action and glucose kinetics in lean compared to reduced obese individuals. Insulin-stimulated glucose disposal was not affected by overfeeding in either group and the only change observed in insulin-suppressed glucose production was a decrease in lean females. The authors speculated that this reduction in insulin action in response to overfeeding may be indirectly involved in the ability of lean women to maintain weight in the obesogenic environment.

One study has attempted to investigate if short-term (3 days) overfeeding (1.4 times estimated energy requirements) impacts on subsequent PA (across 3 days following overfeeding) in obesity resistant compared to obesity prone individuals [82]. No differences were observed in spontaneous PA (assessed using paired inclinometers and accelerometers) or in the number of steps taken per day (assessed using a pedometer) across all study periods between the two groups. The only minor exception was on the third day following controlled overfeeding when obesity prone individuals decreased the amount of time spent walking. This was also reflected in a significantly greater number of steps taken on this day by obesity resistant compared to obesity prone participants (9240 ± 728 vs 7622 ± 932, P<0.05).

Substrate oxidation in response to 3 days of overfeeding (1.4 times estimated energy requirements) was assessed over a 24-hour period using a whole-room calorimeter in obesity resistant and obesity prone participants [80]. Although overfeeding resulted in increased CHO and protein oxidation and decreased fat oxidation in both groups, no significant differences between obesity resistant and obesity prone individuals were observed. Schmidt et al [80] also reported an increase in total energy expenditure in response to overfeeding in obesity resistant and obesity prone participants but no differences between the two groups.

Two initial studies investigated the effect of short-term (2-3 days) overfeeding on appetite responses in thin compared with reduced obese participants [31, 32]. Using a relatively small sample size, Cornier et al [31] observed a decrease in
overall (mean of meals for 2 days) reported hunger with overfeeding (1.5 times estimated energy requirements) in thin (n=13) but not reduced obese individuals (n=9), while overall satiety was increased with overfeeding in both groups but to a greater extent in the thin group. Thirst and nausea ratings were unaffected by overfeeding. In the later slightly larger study, Cornier and colleagues [32] observed a decrease in overall (mean of meals for 2 days) reported hunger (9.6%) and prospective food consumption (10.5%) and an increase in satiety (9.6%) with overfeeding (1.3 times estimated energy requirements) in both thin (n=22) and reduced obese (n=19) participants, with no differences reported between the two groups.

Thomas and colleagues [34] undertook a more comprehensive investigation of the impact of short-term (1 day) over- and under-feeding on appetite responses to a test breakfast meal matched to each feeding intervention in obesity resistant and obesity prone participants. The researchers observed predictable patterns of response to the feeding interventions for fasting and total AUC in both groups, ie decreased fasting hunger and prospective food consumption and increased satiety with overfeeding (40% more energy than estimated energy requirements) and increased hunger and prospective food consumption and decreased satiety with underfeeding (40% less energy than estimated energy requirements). The incremental AUC (iAUC) for hunger, prospective food consumption and satiety did not differ by feeding intervention or group suggesting the differences in total AUC were driven by the differences in the fasting rating. Of more interest is that there were no differences in fasting, total AUC or iAUC for any of the appetite responses due to the feeding intervention between the groups (OR versus OP).

The same cohort and feeding intervention employed by Thomas and colleagues [34] was also used to assess the impact of 1 day of over- and under-feeding on hormone concentrations following the corresponding test breakfast meal. Over- and under-feeding resulted in the maintenance of a significantly lower leptin AUC in obesity resistant compared to obesity prone individuals, while the significantly lower insulin AUC was maintained with overfeeding but the difference between the two groups disappeared with underfeeding. Under eucaloric conditions,
obesity resistant participants displayed a significantly greater ghrelin AUC than obesity prone participants, which was maintained with underfeeding but disappeared with overfeeding. In addition, no differences were reported between the two groups under eucaloric, over- and under-feeding conditions for PYY, GLP-1 and glucose. It must however be noted, that no adjustment for BMI or body composition was attempted in this study. As previously discussed, this is an important consideration with respect to assessment of leptin levels due to the high correlation between adipose tissue mass and leptin concentration in both males and females [110].

All of the studies outlined above employed short-term feeding interventions ie overfeeding or over- and under-feeding for 1 to 3 days. To date, Germain and colleagues [25] have conducted the only long-term feeding study published within the obesity resistance literature. In this study, the hormone, energy balance, and body composition responses of female CTI (who acted as a proxy for ORI) were compared to normal BMI age-matched controls following a 4-week fat overfeeding intervention (+2640 kJ.d⁻¹).

Fasting total and acylated ghrelin levels were increased in controls but were not modified in CTI following overfeeding, resulting in significantly lower levels in CTI compared to controls. A lower level of ghrelin, often referred to as the ‘hunger hormone’, may indicate lower levels of hunger in CTI in response to overfeeding. The iAUC for total and acylated ghrelin, PYY and GLP-1 was calculated from measurements obtained in response to a standardised breakfast meal. Total and acylated ghrelin iAUC increased in CTI and decreased in controls in response to the overfeeding intervention, the result being a significantly larger ghrelin iAUC in CTI compared to controls. Whereas, the iAUC for PYY and GLP-1 was unmodified by overfeeding in CTI, it decreased in controls, resulting in significantly greater PYY and GLP-1 iAUC in CTI versus controls.

Due to the length of the feeding intervention, the study by Germain et al [25] is the only study where the impact of overfeeding on body composition and in particular, BW could be assessed. Interestingly, while BW significantly increased in controls,
as might be expected in response to 4-weeks of overfeeding, BW did not change in CTI. Absolute and relative resting energy expenditure increased significantly in CTI with overfeeding but did not change in controls leading Germain and colleagues [25] to propose this as an adaptive response to the fat overfeeding in order for CTI to maintain their low BW. Overfeeding resulted in a significant increase in the difference between total energy expenditure and energy intake (energy gap) in CTI, but it remained stable in controls, with the overall result being that at the end of the overfeeding period, the energy gap was significant in CTI (P=0.01) but remained non-significant in controls. The authors suggest, that these results, coupled with the anorexigenic hormonal tone in response to overfeeding also observed in this study, may be partly responsible for preventing CTI from gaining BW.

2.5.6.1.1 Summary
With such a disparate collection of studies, in which a variety of variables have been assessed for the most part by only one study, it is not feasible to draw any solid conclusions regarding the impact of energy manipulation on the responses of ORI compared to OSI. In addition, all bar one of the studies involve short-term (1-3 days) feeding interventions and are therefore unable to provide information on the direct impact of energy manipulation of BW control. Furthermore, these short-term studies were all conducted by researchers from the same institution – the Colorado Medical School. Independent confirmation by other researchers outside this group would provide more rigor to the data. However, the findings of Germain and colleagues [25] are intriguing and suggest further investigations using long term overfeeding protocols in specifically defined ORI compared to OSI are warranted.

2.6 Summary
There is a clear lack of research comparing specifically defined obesity resistant individuals (ORI) with obesity susceptible individuals (OSI). The varied definitions used to describe participant groups makes it difficult for direct comparisons to be made between many of the studies. For instance ‘obese’ individuals may not be the
best proxy for OSI as they have passed the point of ‘susceptibility’; equally ‘reduced obese’ are potentially also unsuitable candidates as OSI due to potential alterations in their physiology, including weight loss induced reductions in RMR. ‘Constitutionally thin’ individuals appear to represent a good model for ORI. However, in the studies published to date, data from this group has only been compared to sufferers of anorexia nervosa or normal weight controls - groups not representative of OSI. The majority of studies published to date in the area of obesity resistance have come from only two research groups: one based at the Colorado Medical School in the United States of America [26, 30-34, 79-82] and one based at the Centre Hospitalier Universitaire in Saint-Etienne, France [25, 27, 38, 77].

As outlined in this literature review, there are numerous variables that have the potential to impact upon weight control and the propensity for weight gain and obesity. Unfortunately, what is often the case within the small body of obesity resistance literature is that variables of potential importance have only been included as secondary measures, or to describe the characteristics of participants at baseline prior to an intervention, and subsequently do not form part of the primary objective of the study. As a consequence there are insufficient data to be able to make any conclusive statements regarding the existence of differences between ORI and OSI for hormone concentrations, appetite responses, fat sensitivity, RMR, dietary intake, PA, sedentary behaviour or adaptive thermogenesis. There is some evidence that eating behaviour is different between the two groups with ORI exhibiting lower levels of restrained eating and disinhibition compared to OSI. However, there are still a number of eating behaviour constructs that haven’t received any research attention within the obesity resistance literature.

What is clear is the need for further exploration to determine if and what differences may exist between individuals who are clearly defined as either resistant or susceptible to obesity. Any information regarding how certain individuals can remain lean while living in an obesogenic environment will be
valuable in providing a framework for developing potential strategies to aid those who continually struggle with their weight.
3 The Born to be Lean (B2BL) Study

3.1 Introduction

The obesogenic environment, which is characterised by an abundance of energy-dense, accessible, cheap and palatable food, increased sedentary behaviour and reduced physical activity (PA), has been blamed for the dramatic increase in the prevalence of obesity in the last few decades [9, 10]. Currently it is estimated that more than one third of people world-wide have a BMI ≥ 25 kg.m⁻² (Ng, 2014). Obesity-related non-communicable diseases (NCDs) are a major health challenge and consume a significant proportion of total health care spending [6-8, 52].

Data from studies on temporal changes in body mass index (BMI) indicate that within a population more people are becoming overweight and obese, but there still exists a substantial sector of the population who have remained lean, despite living in an obesogenic environment [15-19]. Information from this group who appear resistant to obesity may assist in developing strategies to benefit those who continually struggle to maintain a healthy body. As yet, few human studies have been undertaken investigating the characteristics of individuals who maintain a healthy body weight (BW) with relative ease (obesity resistant individuals) compared to those who struggle to maintain a healthy BW (obesity susceptible individuals) in the current obesogenic environment. However, it seems highly probable that important differences must exist between these two groups with respect to genetics, metabolism, physiology, behaviour and lifestyle.

The aim of the Born to be Lean (B2BL) study was:

- To compare and contrast physiological, metabolic, behavioural and lifestyle characteristics of individuals who maintain a healthy BW with relative ease i.e. obesity resistant individuals (ORI) with those who struggle to maintain a healthy BW i.e. obesity susceptible individuals (OSI).
3.2 Methods

3.2.1 Overview
Born to be Lean (B2BL) was a cross-sectional study investigating the physiological, metabolic, behavioural and lifestyle characteristics of ORI compared to OSI. Participants underwent assessments of body composition using dual-energy x-ray absorptiometry (DXA), appetite and hormone concentrations in response to a standardised meal, resting metabolic rate (RMR) using indirect calorimetry, dietary intake using a four-day weighed diet record (4DDR), PA and sedentary behaviour using accelerometry and the International Physical Activity Questionnaire (IPAQ), and eating behavior using the Three Factor Eating Questionnaire (TFEQ). Participants also completed a B2BL study questionnaire which included questions relating to BW history, menstrual history (females only), medical history and attitudes and motivations for engaging in exercise.

3.2.2 Participant Characteristics

3.2.2.1 Recruitment
Sixty-five participants (32 males and 33 females) were recruited from the general public in Dunedin, New Zealand. Flyers, designed with specific questions to target obesity resistant and obesity susceptible individuals (Appendix B), were distributed around local supermarkets, placed in local newspapers and attached to emails sent to University of Otago staff.

3.2.2.2 Screening and Eligibility
To be eligible, participants were required to be healthy males or females aged between 20 and 45 years. Participants completed a pre-tested screening questionnaire to determine if they met the study criteria as either an ORI or an OSI (Table 3.1).
Table 3.1. Screening tool for Obesity Resistant Individuals (ORI) and Obesity Susceptible Individuals (OSI)

Statement

1. I am a person who can eat whatever I like without gaining weight
2. I am a person who maintains my weight easily
3. I am a person who loses weight easily
4. I am a person who finds it difficult to put on weight
5. I am a person who needs to eat small amounts of food to manage my weight
6. I am a person who gains weight easily

Participants were classified as ORI if they answered positively to any of the statements 1 – 4. Conversely, participants were classified as OSI if they answered positively to either or both of the statements 5 – 6. Participants were excluded if they did not answer positively to any of the screening tool statements, or if they were unable to be clearly classified as ORI or OSI using the criteria outlined above. The percentage of male and female ORI and OSI answering positively to each screening tool statement is shown in Table 3.2.

Table 3.2. Percentage of obesity resistant individuals (ORI) and obesity susceptible individuals (OSI) responding positively to each screening tool statement

<table>
<thead>
<tr>
<th>Statement</th>
<th>ORI</th>
<th>OSI</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Females</td>
<td>Males</td>
</tr>
<tr>
<td>1. I am a person who can eat whatever I like without gaining weight</td>
<td>88.2</td>
<td>92.9</td>
</tr>
<tr>
<td>2. I am a person who maintains my weight easily</td>
<td>100</td>
<td>92.9</td>
</tr>
<tr>
<td>3. I am a person who loses weight easily</td>
<td>41.1</td>
<td>50.0</td>
</tr>
<tr>
<td>4. I am a person who finds it difficult to put on weight</td>
<td>76.5</td>
<td>92.9</td>
</tr>
<tr>
<td>5. I am a person who needs to eat small amounts of food to manage my weight</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>6. I am a person who gains weight easily</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

ORI: obesity resistant individuals, OSI: obesity susceptible individuals
Exclusion criteria also included presence of chronic disease, menopause, smoking, pregnancy, lactation, previous history of an eating disorder and presence of a thyroid disorder or other medical condition/s that affect metabolic rate. Of the 76 respondents assessed for eligibility, 11 were excluded from entering the study. Ten were unable to be clearly classified as ORI or OSI and 1 had a previous history of an eating disorder. In total 34 ORI and 31 OSI were recruited to take part in the study following screening (Figure 3.1).

### 3.2.2.3 Final Cohort

Following entry into the study, but before beginning any of the study assessments, one participant withdrew due to illness. One further participant was retrospectively excluded when analysis of the blood samples obtained as part of the hormone concentration assessment revealed undiagnosed type II diabetes (a study exclusion criterion). The final number of participants whose data were included in the analyses was 63, consisting of 34 ORI (17 females, 17 males) and 29 OSI (16 females, 13 males) (Figure 3.1).

Following screening, participants also completed a questionnaire regarding past-weight history (Appendix C). Weight history information was not used to further categorise the participants, but it did assist in confirming their status as obesity resistant or obesity susceptible individuals. When entering the study participants self-reported being weight stable (i.e. ≤ 2 kg weight change in the previous 12 weeks). Obesity resistant individuals had a BMI of 17.5 - 27.7 kg.m⁻², had always been lean (as indicated by self-reported weight history), and found it difficult to gain but not lose weight. In contrast, OSI had a BMI of 21.6 – 44.0 kg.m⁻², were likely to experience fluctuations in weight (as indicated by self-reported weight history), and found it difficult to lose but not gain weight.

The schedule of clinic appointments for the assessments conducted in the B2BL study is shown in Figure 3.2
Figure 3.1. Number of obesity resistant females (ORF) and males (ORM) and obesity susceptible females (OSF) and males (OSM) recruited and completing each component of the Born to be Lean (B2BL) Study.
3.2.3 Ethical Approval and Informed Consent

The study protocol was approved by the Human Ethics Committee of the University of Otago, New Zealand (Appendix D). All participants provided written informed consent (Appendix E, F).

3.2.4 Body Composition Assessment

3.2.4.1 Anthropometric Measurements

Body weight (BW) was measured in the fasting state in light clothing without footwear on calibrated electronic scales (Model TBF-310, Wedderburn) that measured to the nearest 0.1 kg. Height was measured to the nearest millimetre using a stadiometer (Department of Human Nutrition, University of Otago) with footwear removed. Participants were positioned with their heels and back against the vertical backboard of the stadiometer and their head aligned in the Frankfort plane. Participants were asked to inhale deeply while maintaining this body...
position. The stadiometer headboard was then lowered until it rested firmly on
the head of the participant and the measurement of height was read at eye-level
from the vertical scale of the stadiometer and recorded. Body mass index (BMI)
was calculated by dividing BW in kilograms by the height in metres squared.

Waist circumference (WC) was measured using the International Society for the
Advancement of Kinaanthropometry (ISAK) protocol [423] that is, at the level of the
narrowest point between the bottom of the 10th rib and the border of the iliac crest
using a flexible metal tape (Lufkin W606PM) and the arms folded across the thorax.
The measurement was recorded at the end of normal expiration to the nearest
millimetre. All anthropometric measurements were taken twice. If measurements
differed by more than 1% a third measurement was taken [423]. The final value
for each individual anthropometric variable was calculated as the mean of 2
measurements or the median of 3 measurements [423, 424].

3.2.4.2 Body Composition
Body composition including lean body mass (LBM), fat mass and percentage body
fat (%BF) was measured using DXA (DPX-L Scanner, Lunar Corp, Cincinnati, OH,
USA) using software version 1.35 (Lunar, Cincinnati, OH, USA) by a single
experienced technician. Anthropometric and body composition measurements
were obtained for all 63 participants (Figure 3.1).

3.2.5 Hormone Concentrations and Appetite Response
Assessment
3.2.5.1 Experimental Design and Procedures
Sixty one participants (33 ORI (16 females, 17 males) and 28 OSI (15 females, 13
males), (Figure 3.1) attended a 4 h clinic visit at the Department of Human
Nutrition, University of Otago. Participants arrived at the clinic after an overnight
fast of at least 10 h. A fasting fingerprick blood sample using a disposable lancet
was taken for measurement of ghrelin (active), and total peptide YY (PYY), leptin,
glucose and insulin (See section 3.2.5.3). Fingerprick capillary blood samples were
collected in micro-centrifuge tubes containing potassium EDTA. This was followed by the consumption of a standardised meal that participants were asked to consume within 15 min. Further fingerprick capillary blood samples were collected at 15, 30, 60, 120 and 180 min following the start of ingestion of the meal. Participants also completed an appetite questionnaire at each blood sampling time-point (see section 3.2.5.4).

3.2.5.2 The Standardised Meal
The composition of the standardised meal was comparable to that used by Doucet et al, [425]. Using a protocol very similar to our study design, Doucet and colleagues [425] investigated total ghrelin and PYY concentrations and appetite responses to a standardised meal over a 3 h period in healthy premenopausal women. This standardised meal was designed to provide 2400 kJ (575 kcal) of energy with 57, 30 and 13 percent of total energy intake (TEI) from carbohydrate (CHO), fat and protein, respectively.

Table 3.3. Food and macronutrient composition of the standardised meal

<table>
<thead>
<tr>
<th>Food</th>
<th>Females</th>
<th>Males</th>
</tr>
</thead>
<tbody>
<tr>
<td>muesli (g)</td>
<td>93</td>
<td>112</td>
</tr>
<tr>
<td>milk (g)</td>
<td>83</td>
<td>100</td>
</tr>
<tr>
<td>yoghurt (g)</td>
<td>150</td>
<td>180</td>
</tr>
<tr>
<td>orange juice (ml)</td>
<td>240</td>
<td>240</td>
</tr>
<tr>
<td>Nutrients</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Energy (kJ)</td>
<td>2440</td>
<td>2928</td>
</tr>
<tr>
<td>Energy (kcal)</td>
<td>584</td>
<td>700</td>
</tr>
<tr>
<td>CHO (g)</td>
<td>83 (55)</td>
<td>100 (55)</td>
</tr>
<tr>
<td>Fat (g)</td>
<td>19 (29)</td>
<td>23 (29)</td>
</tr>
<tr>
<td>Protein (g)</td>
<td>21 (15)</td>
<td>26 (15)</td>
</tr>
<tr>
<td>Fibre (g)</td>
<td>5.6</td>
<td>6.7</td>
</tr>
</tbody>
</table>

Values for macronutrients are expressed as grams (%TEI)
%TEI = percentage of total energy intake, CHO = carbohydrate

The composition of the standardised meal used in the present study is shown in Table 3.3. An additional approximately 500kJ of energy was provided to the male...
participants in the present study. The meal was comprised of a muesli cereal (containing oats, wheat germ, Kelloggs Special K®, brown sugar, desiccated coconut, skim milk powder, full fat milk, canola oil, almonds, sultanas, dried apricots, sunflower seeds), milk, yoghurt, and orange juice (Table 3.3). Participants were required to consume the entire standardised meal within a 15 min time period. Because the response of important study variables (namely ghrelin, PYY, and appetite scores) [93, 96] has been shown to be proportional to caloric intake and because this study was cross-sectional, we decided to fix caloric intake for each sex to reduce inter-individual variability.

3.2.5.3 Sampling and Biochemical Analysis

Fingerprick capillary blood samples (1 mL) were collected in 1.5 mL micro-centrifuge tubes containing 10 µL of sodium EDTA. Immediately prior to blood collection, 10 µL of serine protease inhibitor was added for the ghrelin (active) measurement. Upon blood collection the tubes were gently inverted and stored on ice. Samples were then centrifuged for 15 min to obtain plasma, which was stored in micro-centrifuge tubes at -80 ºC until assay. Whole capillary blood was also collected into a HemoCue® cuvette and blood glucose concentration measured using a HemoCue Glucose 201+ Analyzer® (Helsingborg, Sweden).

Ghrelin (active), total PYY, leptin, and insulin were analysed using immunoassay (Human Gut Hormone Panel LINCOplex Kit, LINCO Research, St. Charles, MO, USA). The minimum detectable concentrations for the hormones were: 1.8 pg.ml⁻¹ for ghrelin (active), 8.4 pg.ml⁻¹ for total PYY, 157.2 pg.ml⁻¹ for leptin, and 44.5 pg.ml⁻¹ for insulin. The coefficient of variation for measurements of ghrelin, total PYY, leptin, and insulin were 13.0%, 8.1%, 11.8%, and 8.4% respectively.

Area under the curve (AUC) for ghrelin, total PYY, leptin, glucose and insulin was calculated by the trapezoid method [426, 427]. The observed peak/nadir and time to peak/nadir were recorded.
3.2.5.4  Appetite Ratings

At each blood sampling time-point (0, 15, 30, 60, 120, 180 min), participants completed a series of appetite related questionnaires using a 100 mm visual analogue scale (VAS) [114, 115]. The appetite-rating questionnaires included questions on hunger, preoccupation with thoughts of food, desire to eat and fullness. In relation to each question, there were extreme states anchored at either end of the line i.e. at 0 mm on the left side and 100 mm on the right side. The questions and VAS administered are outlined in Figure 3.3.

How hungry are you right now?

[-----------------------------------------------]
Not at all hungry  As hungry as I have ever felt

How strong is your desire to eat right now?

[-----------------------------------------------]
Very weak  Very strong

How full are you right now?

[-----------------------------------------------]
Not at all full  As full as I have ever felt

Do you have any preoccupation with thoughts of food right now?

[-----------------------------------------------]
No thoughts of food  Very preoccupied, difficult to concentrate

Figure 3.3. Appetite rating questions and visual analogue scales (VAS)

The VAS were measured by an investigator blinded to the study group. Area under the curve (AUC) for each rating was calculated by the trapezoid method [426]. The observed peak/nadir and time to peak/nadir were recorded [428].

3.2.6  Resting Metabolic Rate (RMR) Assessment

3.2.6.1  Indirect Calorimetry

Resting metabolic rate (RMR) was measured in 62 participants (Figure 3.1) using indirect calorimetry based on best practice methods [130]. One participant chose not to undergo this measurement. Menstruating females were measured during the follicular phase of the menstrual cycle, as metabolic rate can be affected by the thermic effect of progesterone during the luteal phase [429-431]. On a separate occasion, thyroid function was measured in all participants in order to detect any individuals who may have disordered function which could affect metabolic rate. The assessment was conducted in an exercise physiology laboratory at the School
of Physical Education, University of Otago. All testing was conducted in a quiet, mildly lit and heated (average 20.5°C) room. Environmental settings were kept consistent for all participants to ensure RMR measurements were not influenced by sound, light or temperature. Participants were asked to fast overnight and to abstain from alcohol and caffeine for at least ten hours prior to the test. Participants were also asked to avoid engaging in strenuous activity in the 24 h prior to this assessment. Testing was undertaken between 6 am and 10 am to ensure participants were not fasting for long periods of time during waking hours.

Participants rested for 15 min in a semi-recumbent position and were instructed not to fall asleep. Following the rest period, participants breathed for a 15 min period through a facemask. Expired gas was collected using a Sensormedics 2900 metabolic cart (Sensormedics, California, USA). Gas analyzers were calibrated prior to each test using set O₂ (26%) and O₂/CO₂ (16% & 4%) mixtures before testing began each morning, and again if more than two tests were carried out in one morning. Volume was also calibrated prior to each test using a standard 3 L syringe. Participants were provided with breakfast following testing.

3.2.6.2 Data Analysis and Calculations

The first 5 min of data collection were discarded and the remaining 10 min used to determine a 4 min period having a coefficient of variation (CV) for \( \overline{V_O_2} \) (L.min\(^{-1}\)) and \( \overline{V_CO_2} \) (L.min\(^{-1}\)) of ≤10% for analysis. If these criteria were not reached (n=22) values for the lowest CV were used in the analysis. The abbreviated Weir equation [151] was used to determine RMR from mean \( \overline{V_O_2} \) (L.min\(^{-1}\)) and \( \overline{V_CO_2} \) (L.min\(^{-1}\)), as used previously [432]:

\[
RMR \text{ (kcal.d}^{-1} \text{)} = (3.941 \times \overline{V_O_2} + 1.106 \times \overline{V_CO_2}) \times 1440.
\]

Of the 62 participants whose RMR was measured, five were excluded from final analysis due to failure to meet inclusion criteria. Four female participants and one male participant had a respiratory exchange ratio (RER) value above 1, indicating pre-test protocol violations or measurement inaccuracy. The final sample
consisted of 57 participants 31 ORI (14 females, 17 males) and 26 OSI (14 females, 12 males). (Figure 3.1).

3.2.6.3 Comparison with Published Resting Metabolic Rate (RMR) Prediction Equations

Predicted RMR was calculated using three well-known previously published prediction equations. The FAO/WHO/UNU (Food and Agricultural Organisation/World Health Organisation/United Nations University) equations [152] were developed using data from Schofield [433], Schofield [434] and James [435] derived mostly from young European men and women. The Oxford Equations have been developed using a dataset of 10 552 RMR values that excluded all the Italian subjects from the FAO/WHO/UNU equation dataset and included a much larger number of people from the tropics [154]. The Miflin-St Jeor equation was derived from a sample of normal-weight, overweight, obese and severely obese individuals [153].

FAO/WHO/UNU Equations (kJ.d⁻¹):

Females: 18-30 y  55.6 x weight + 1397.4 x height + 146
           31-60 y  36.4 x weight – 104.6 x height + 3619
Males:   18-30 y  64.4 x weight – 113.0 x height + 3000
          31-60 y  47.2 x weight + 66.9 x height + 3769

weight (kg), height (m)

Oxford Equations (kJ.d⁻¹):

Females: 18-30 y  (0.0546 x weight + 2.33) x 1000
           31-60 y  (0.0407 x weight + 2.90) x 1000
Males:   18-30 y  (0.0669 x weight + 2.28) x 1000
          31-60 y  (0.0592 x weight + 2.48) x 1000

weight (kg), height (cm), age (y)

Miflin-St Jeor Equations (kJ.d⁻¹):

Females:  (9.99 x weight + 6.25 x height – 4.92 x age – 161) x 4.18
Males:   (9.99 x weight + 6.25 x height – 4.92 x age + 5) x 4.18

weight (kg), height (cm), age (y)
These particular equations were selected for study because of their popular use by health professionals. The Oxford equations have recently been adopted by Dietitians New Zealand for estimating RMR [149], while the Miflin-St Jeor equations are recommended for estimating RMR in overweight and obese individuals by the Academy of Nutrition and Dietetics (formally the American Dietetic Association) [150].

Predicted RMR, calculated using the equations detailed above, was compared to measured RMR. In addition, the proportion of participants whose RMR was predicted to within 10% of the measured RMR was also determined.

### 3.2.7 Dietary Intake Assessment

#### 3.2.7.1 Energy and Nutrient Intake

A 4DDR (Appendix G) of all food and beverages consumed both in and away from the home was collected from participants. The non-consecutive four days included three week days and one weekend day over a one week period in the same week as the accelerometry assessment. These were the only two assessments undertaken during this time to avoid overburdening the participants.

Food and beverage intake was recorded at the time of consumption using kitchen scales (Salter Electronic, Salter Housewares Ltd., Kent, UK) accurate to within ± 1 gram. Participants received detailed verbal instructions from a trained researcher on how to collect a 4DDR and further written instructions were included in the 4DDR recording booklet itself (Appendix G). These instructions included guidelines on how to describe the foods and beverages that were consumed in detail eg inclusion of brand names, any additions to foods/beverages such as salt, sugar, sauces etc, and how the foods/beverages were prepared and cooked if appropriate. For situations where direct weighing of foods and beverages was not possible eg when eating in a restaurant or eating food prepared and/or cooked by someone else; participants were given instructions on how to estimate the amount consumed using common household measures eg cups, teaspoons, tablespoons etc, using the weights marked on packages and by using a booklet containing
photographs of different portion sizes of common foods that was provided to them (Appendix H). Instructions were also given on how to record the consumption of mixed food dishes by providing a list of ingredients and the amount included in the total dish and the proportion of the mixed dish consumed.

All 63 participants received information on keeping a diet record, measuring scales and a recording booklet. Four participants did not return the 4DDR recording booklet and two participants returned incomplete records (≤ 2 days completed) and were subsequently excluded from the dietary intake analysis. The final sample consisted of 57 participants (31 ORI (16 females, 15 males) and 26 OSI (15 females, 11 males) (Figure 3.1).

The completed 4DDRs were analysed to provide an estimate of average daily reported energy and nutrient intakes using Kai-calculator (version 1.08) the dietary assessment software developed in the Department of Human Nutrition, University of Otago. The food composition database includes current and previous versions of FOODfiles (2010v2) from Plant and Food Research Ltd and selected recipes calculated for the 2008/09 New Zealand Adult Nutrition Survey [436]. To ensure consistency and accuracy in data-entry decisions when substitutions had to be made, the candidate entered all the diet records and maintained comprehensive detailed notes regarding food and beverage item substitutions.

Data are presented as absolute intakes of energy and intake of energy relative to BW, absolute intakes and intake as a percentage of TEI of energy-yielding nutrients and intake of fibre, cholesterol and selected micronutrients relative to energy intake (per 1000 kJ).

3.2.7.2 Food Group Classification
All food and beverages reported were coded to 17 main food groups (Table 3.4) based on the classifications used by Smith et al [437].
As outlined previously (see section 3.2.7.1), for mixed dishes, participants were asked to report the recipe (both ingredients and amounts) so for all foods and beverages, ingredients were coded into separate food groups. For example, for a ham and cheese sandwich, the bread would be coded into the bread food group, the margarine into butter and margarine, the ham into sausages and processed
meat and the cheese into the cheese food group. This is in contrast to the study by Smith et al [437] where participants were not always able to report all detail of the ingredients in mixed dishes. In this situation, Smith et al [437] obtained a description of the food and it was coded according to the main food component. For example a cheeseburger would be coded into the sub-food group burgers and hotdogs within the main food group of bread based dishes.

To account for these differences in data collection and a much smaller sample size in the present study, the following modifications were applied to the food classification system used by Smith et al [437]:

- ‘pasta’ and ‘pasta-based dishes’ and ‘rice’ and ‘rice-based dishes’ were renamed ‘grains, pasta and cereals’ and combined with ‘breads and breakfast cereals’ to form ‘bread, grains, pasta, cereals and breakfast cereals’
- ‘potato’ was expanded to create ‘potato, kumara and taro’
- ‘milk’, ‘cheese’ and ‘dairy product’ groups were combined to form ‘milk, cheese and dairy products’
- ‘butter’, ‘margarine’ and ‘fats and oils’ were combined to form ‘butter, margarine, fats and oils’
- ‘lamb and mutton’, ‘beef’, ‘pork’, and ‘other meat’ were combined with ‘poultry’ and ‘fish and seafood’ to form ‘meat, poultry, fish and seafood’
- ‘biscuits, cakes and muffins’ and ‘puddings’ were combined with ‘sugar and confectionery’ to form ‘cakes, biscuits, puddings, sugar and confectionery’
- ‘snacks and snack bars’ was renamed ‘snack foods’
- ‘sauces’ was expanded to create ‘savoury sauces and spreads’
- two new food groups ‘fast foods’ and ‘meat alternatives’ were created
- ‘hot beverages’ and ‘water’ were combined to form ‘hot beverages and water’
- ‘juices’ and ‘sweetened beverages’ were combined to form ‘juices and sweetened beverages’
- ‘bread-based dishes’, ‘pies’, and ‘soup’ were removed as food items found in these food groups could now be classified into other food groups.
The percentage contribution of each food group to energy intake was calculated. Five food groups (‘eggs’, ‘hot beverages and water’, ‘meat alternatives’, ‘savoury sauces and spreads’ and ‘potato, kumara and taro’) each contributed less than 3% to average daily total energy intake and were removed from the analysis.

3.2.7.3 Sensitivity Analysis
A sensitivity analysis was completed to examine whether the removal of low energy reporters (LER) altered our results. Participants with an energy intake to RMR ratio (EI:RMR) of <1.06 were classified as LER using the Goldberg method as outlined by Gibson (2005) [438]. For the five participants whose data was removed from the RMR analysis, the FAO/WHO/UNU (1985) [152] equations were used to estimate RMR (RMR\textsubscript{est}) and LER classified as EI:RMR\textsubscript{est} <1.06.

3.2.8 Physical Activity (PA) and Sedentary Behaviour Assessment
3.2.8.1 Accelerometry
3.2.8.1.1 Accelerometer Set-up and Participant Instructions
Physical activity (PA) was measured using Actical accelerometers (Mini Mitter Co Inc, Bend, Oregon, USA). The Actical is a small (28 x 27 x 10 mm), light (17 g) device that uses an omnidirectional accelerometer. It is able to measure accelerations in the range of 0.05-2.0 G and is sensitive to movements in the range of 0.35 – 3.5 Hz [439]. In accordance with the manufacturers instructions, the Actical was programmed for each participant by entering their height, weight, age and sex and initialised to collect data in 15 s epochs.

Participants were instructed to wear the Actical accelerometer attached to an elasticised band on the right hip at waist level for at least 7 consecutive days. As the Actical is waterproof case it can withstand normal daily activities such as showering, bathing, and swimming. Participants were instructed to wear the accelerometer at all times except when sleeping, or engaging in activities potentially harmful to the device (eg contact or combat sports). Detailed instructions on how to wear the accelerometer were given to the participants.
(Appendix I). Participants were blinded to information on the PA level as the Actical is not fitted with a data screen and therefore cannot provide the wearer with any feedback.

3.2.8.1.2 Data Download, Quality Control and Analysis
After at least 7 consecutive days of data acquisition, accelerometers were collected and data was downloaded through the ActiReader serial port interface (Mini Mitter Co Inc, Bend, Oregon, USA). As two participants chose not to wear the accelerometer, the final sample available for downloading was 61.

Data were scored and interpreted using the MeterPlus Version 4.3 software from Santech, Inc. (www.meterplussoftware.com). The Actical has been validated to measure PA in adults [440]. The following quality control and data reduction procedures, used in the analysis of accelerometer data from the National Health and Nutrition Examination Survey (NHANES) [299] and the Canadian Health Measures Survey (CHMS) [441], were applied to this data set. A spurious data threshold of 20,000 counts per minute (cpm) was used. This threshold excludes biologically implausible movement data, but still enables the capture of movement counts generated by activities such as high-speed running (14 to 16 km/h) [442]. A valid day was defined as having 10 or more hours of accelerometer wear time [299, 441]. Wear time was calculated by subtracting non-wear time from 24 h. Non-wear time was defined by a period of at least 60 consecutive minutes of zero activity counts, with allowance for 1 to 2 min of counts between 0 and 100.

Participants with four or more valid days were retained for analyses. Following the accelerometer data download, four participant files were found to contain no data suggesting accelerometer malfunction or the participants did not wear the accelerometer. An additional three participant files contained only one valid day, again suggestive of accelerometer malfunction, possible incorrect positioning of the device or the participants only actually wore the device for one day. The final sample available for analysis consisted of 54 participants (29 ORI (12 females, 17 males) and 25 OSI (14 females, 11 males) (Figure 3.1).
The amount of PA as measured by the Actical accelerometer was analysed and is presented in three ways:

1) mean counts per minute
2) estimates of time spent in various levels of movement intensity
3) an estimate of adherence to PA recommendations

3.2.8.1.3 Mean Counts Per Minute (cpm)
Mean counts per minute (cpm) were calculated by dividing total activity counts each day by the number of minutes of wear time in that day. Counts per minute (cpm) were calculated for each valid day and the mean obtained.

3.2.8.1.4 Time Spent in Various Levels of Movement Intensity
For the analysis of time spent in various levels of movement intensity, cut-points specific to the Actical accelerometer and corresponding to sedentary [302], light, moderate and vigorous [443] levels were applied (Table 3.5). Time spent performing activity at each level of movement intensity (sedentary, light, moderate, vigorous, or moderate and vigorous combined) was determined by summing minutes in a day where the count met the criterion for that intensity.

Table 3.5. Physical activity (PA) intensity cut-points for the Actical accelerometer

<table>
<thead>
<tr>
<th>Intensity</th>
<th>Metabolic Equivalent of Task (MET)</th>
<th>Actical Accelerometer count range (cpm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sedentary</td>
<td>1 to &lt; 2</td>
<td>&lt; 100</td>
</tr>
<tr>
<td>Light</td>
<td>2 to &lt; 3</td>
<td>100 to &lt; 1535</td>
</tr>
<tr>
<td>Moderate</td>
<td>3 to &lt; 6</td>
<td>1535 to &lt; 3962</td>
</tr>
<tr>
<td>Vigorous</td>
<td>6 or more</td>
<td>3962 or more</td>
</tr>
</tbody>
</table>

cpm = counts per minute
Table adapted from [441]

3.2.8.1.5 Adherence to Physical Activity (PA) Recommendations
The WHO Global Recommendation on Physical Activity for Health [268], along with a number of country-specific PA recommendations, including the Physical Activity Guidelines for Americans [266] are as follows:
• Adults aged 18-64 should do at least 150 min of moderate-intensity aerobic PA throughout the week or do at least 75 min of vigorous-intensity aerobic PA throughout the week or an equivalent combination of moderate-intensity and vigorous-intensity physical activity (MVPA).
• Aerobic activity should be performed in bouts of at least 10 min duration.
• For additional health benefits, adults should increase their moderate-intensity aerobic PA to 300 min per week, or engage in 150 min of vigorous-intensity aerobic PA per week, or an equivalent combination of MVPA.
• Muscle-strengthening activities should be done involving major muscle groups on 2 or more days a week.

In addition, to ensure the activity is undertaken throughout the week, the New Zealand Ministry of Health [267] recommends adults should be doing at least 30 min of moderate-intensity PA at least 5 days a week.

In order to compare accelerometer data with PA recommendations, a 10 min activity bout was defined as 10 consecutive minutes of observations above the moderate movement intensity cut-point ($\geq 1535$ cpm), with allowance for a maximum of two minutes falling below the cut-point threshold during that period [441]. Mean daily time in bouts was calculated across the first seven valid days in order to include 5 week days and 2 weekend days.

Adherence to PA recommendations were examined in two ways:

1) A weekly sum of 150 or more minutes of MVPA per week (7 days) accumulated in bouts of at least 10 min.

2) Probability of accumulating at least 30 min of MVPA in bouts of at least 10 min on at least 5 days of the week (ie 5 out of 7 days).

The analysis of adherence to PA recommendations required 7 valid days in order to access accumulation of MVPA over a week. Two participant files were found to contain only 4 valid days and were therefore excluded from this analysis. The final sample available for analysis of adherence to PA recommendations consisted of 52
participants (27 ORI (12 females, 15 males) and 25 OSI (14 females, 11 males) (Figure 3.1).

3.2.8.2 **International Physical Activity Questionnaire (IPAQ)**

The International Physical Activity Questionnaire (IPAQ) is a validated questionnaire, which measures various components of PA [288]. For the purposes of this study, the self-administered 'long' format version was used. This version of the questionnaire asks respondents to describe the PA they have performed in the previous seven days. It is comprised of 5 sections: work-related PA; transportation-related PA; domestic and garden activities; leisure-time PA; and time spent sitting (Appendix J).

3.2.8.2.1 **Data Processing**

The data derived from the IPAQ was processed and scored according to the methods recommended by IPAQ Research Committee (2005) [444]. Initial data cleaning and processing included the following:

- Conversion of responses provided in hours and minutes into minutes.
- Identification of any unreasonably high values and subsequent exclusion from the analysis of all cases in which the sum total of all walking, moderate and vigorous time variables is greater than 960 min (16 hours) per day.
- Identification of activities that occurred for at least 10 min in duration for inclusion in the calculation of summary scores.
- Responses indicating activity of less than 10 min in duration recoded to 'zero'.

3.2.8.2.2 **Scoring of Continuous Variables**

The items in the 'long' IPAQ form are structured to provide separate domain-specific scores for walking, moderate-intensity and vigorous-intensity activity within each of the work, transportation, domestic and gardening work and leisure-time domains. Domain-specific scores reported in MET-min.wk⁻¹ were calculated by summation of the scores for walking, moderate-intensity and vigorous-intensity activities within the specific domain. Only participants who responded with a 'yes'
to the question “Do you currently have a job or do any unpaid work outside the home?” were included in the calculations for the work-related PA domain score.

Activity-specific scores also reported in MET-min.wk\(^{-1}\) were calculated by summation of the scores for the specific type of activity across domains. Finally, a total PA score reported in MET-min.wk\(^{-1}\) was calculated by summation of activity-specific scores for walking, moderate-intensity and vigorous-intensity activity. A more detailed description of the method used for calculating the domain-specific, activity-specific and total PA scores can be found in Appendix K.

3.2.8.2.3 Scoring of Categorical Variables
There are three levels of PA (‘Low’, ‘Moderate’ and ‘High’) the IPAQ Research Committee have proposed to classify respondents [444]. The ‘Moderate’ category is a level of activity equivalent to 30 min of at least moderate-intensity PA on most days and is equivalent to the population PA recommendation outlined above in section 3.1.10.1.5. Specifically the pattern of activity to be classified as ‘Moderate’ is either of the following criteria:

a) 3 or more days of vigorous-intensity activity of at least 20 min.d\(^{-1}\)

OR

b) 5 or more days of moderate-intensity activity and/or walking of at least 20 min.d\(^{-1}\)

OR

c) 5 or more days of any combination of walking, moderate-intensity or vigorous-intensity activities achieving a minimum total PA of at least 600 MET-min.wk\(^{-1}\)

Greater health benefits are associated with increased levels of PA [266-268]. For this reason, the ‘High’ category was developed to describe higher levels of participation. Specifically the pattern of activity to be classified as ‘High’ is either of the following criteria:

a) vigorous-intensity activity on at least 3 days achieving a minimum total PA of at least 1500 MET-min.wk\(^{-1}\)

OR
b) 7 or more days of any combination of walking, moderate-intensity or vigorous-intensity activities achieving a minimum total PA of at least 3000 MET-min.wk⁻¹

The ‘Low’ category is simply defined as not meeting any of the criteria for either the ‘Moderate’ or ‘High’ categories. Processing and scoring of the categorical data obtained from the IPAQ was conducted according to the IPAQ Research Committee guidelines.

3.2.8.2.4 Scoring of Sitting Variables
The ‘long’ IPAQ form estimates the time spent sitting on a typical weekday, weekend day and while travelling in a motor vehicle e.g. train, bus, car etc (obtained from the transport-related PA domain questions). Total sitting minutes per week, average sitting total minutes per day, total sitting including transport minutes per week and average sitting including transport total minutes per day were calculated according to the guidelines of the IPAQ Research Committee [444] (Appendix K).

The IPAQ questionnaire was given to participants to complete while they attended the 4 h clinic visit for the assessment of hormone concentrations and appetite responses. One participant did not complete the questionnaire, as they did not attend the 4 h clinic visit. Two participants did not manage to finish the questionnaire during the 4 h clinic visit. They were asked to finish the questionnaire in their own time and return the completed questionnaire to the researchers at their convenience; neither participant did so. The final sample of completed IPAQs consisted of 60 participants (34 ORI (17 females, 17 males) and 26 OSI (14 females, 12 males) (Figure 3.1).

3.2.8.3 Attitudes to Exercise
As part of the B2BL study questionnaire, participants completed a section regarding their attitudes and motivations for engaging in exercise. This section of the questionnaire contained 19 statements relating to intrinsic and extrinsic
motivators, feelings and emotions associated with exercise eg “If I cannot exercise I feel frustrated”, “I exercise to keep healthy” and “I exercise to look attractive”. The 19 statements were selected from the 29 item validated Exercise Dependence Questionnaire [445]. The questions not included in the attitudes to exercise questionnaire related to the ‘interference with social/family/work life’, ‘insight into problem’, ‘exercise for social reasons’ and ‘stereotyped behaviour’ factors identified in the Exercise Dependence Questionnaire. Participants were presented with five options (strongly disagree, disagree, neither agree nor disagree, agree, and strongly agree) and asked to identify the option that most applied to them in relation to each statement (Appendix L). For analysis, the response option for each statement was re-coded as follows: 1 = strongly disagree, 2 = disagree, 3 = neither agree nor disagree, 4 = agree, and 5 = strongly agree. A total of 61 participants (34 ORI (17 females, 17 males) and 27 OSI (15 females, 12 males) (Figure 3.1) completed this section of the B2BL study questionnaire.

3.2.9 Eating Behaviour Assessment

3.2.9.1 Three-Factor Eating Questionnaire (TFEQ)

The Three-Factor Eating Questionnaire (TFEQ) is a self-administered validated questionnaire, which measures the eating behaviour constructs of restrained eating, disinhibition and hunger [308] (Appendix M). The subscales of the TFEQ are described in Table 3.6.

The TEFQ comprises of 51 statements separated into two parts. The first part contains 36 statements to which respondents are asked to indicate whether they consider the statement to be a ‘true’ or ‘false’ reflection for them. The second part contains 15 statements. Respondents are asked to select one of four options that indicate the most appropriate response to that statement. Details of the scoring of the TEFQ can be found in Appendix M. The TFEQ was presented and completed by participants during the breakfast that followed the RMR assessment. One participant chose not to undergo the RMR measurement and another participant was unable to stay after the RMR measurement, so both did not attend the post-
testing breakfast. The final sample who completed the TFEQ consisted of 61 participants (33 ORI (16 females, 17 males) and 28 OSI (15 females, 13 males).

### Table 3.6. Subscale descriptions for the Three-Factor Eating Questionnaire (TEFQ)

<table>
<thead>
<tr>
<th>Subscale</th>
<th>Description</th>
<th>Example Behaviours</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Restrained Eating</td>
<td>Concern over weight control and engaging in strategies to achieve this</td>
<td>Avoiding fattening foods, eating small portions, and stopping eating before reaching satiation in order to limit food intake.</td>
</tr>
<tr>
<td>2. Disinhibition</td>
<td>A tendency to over-eating and eating opportunistically in an obesogenic environment</td>
<td>Eating in response to negative affect, over eating when others are eating, not being able to resist stimulation to eat and overeating in response to the palatability of food.</td>
</tr>
<tr>
<td>3. Hunger</td>
<td>The extent to which hunger feelings are perceived and the extent to which such feelings evoke food intake</td>
<td>Feeling so hungry that an individual eats more than three times per day, or feeling so hungry that their stomach feels like a bottomless pit</td>
</tr>
</tbody>
</table>

Descriptions and examples adapted from [331]

### 3.2.9.2 Eating Frequency

As part of the 4DDR recording process, participants were asked to document the times they began and ended each eating event. This enabled a calculation of eating frequency to be conducted. The number of eating occasions per day was defined as any energetic solid, semi-solid or liquid food or drink that provided at least 201 kJ (50 kcal) with a minimum time interval between occasions (from the end of the previous occasion to the start of the next occasion) of at least 15 min [410]. This definition allowed the inclusion of all eating occasions in the calculation of eating frequency regardless of whether the subject considered the event to be a ‘meal’ or a ‘snack’. The number of eating occasions (all meals and snacks) for each participant for each day of the 4DDR was tallied. Eating frequency was then calculated for each participant as the mean number of eating occasions per day [446].
3.2.9.3  **Time Spent Eating**
The information on the time each eating occasion began and ended was also used to calculate the average amount of time each participant spent eating per day. The length of each eating occasion was determined and tallied for each day of the 4DDR. The average amount of time spent eating per day was then calculated for each participant over the four-day period.

3.2.10  **Statistical Analysis**
Statistical analysis was performed using STATA Version 12.1 (STATA Inc., College Station, TX, USA). All statistical tests were two-sided and P<0.05 was considered statistically significant.

3.2.10.1  **Sample Size and Participant Characteristics**
The primary outcome measure to be assessed was the postprandial change in ghrelin. Thirty participants per group (ORI and OSI) were required to detect a difference of 5% in the serial measurements of ghrelin with a power of 90% and alpha 0.05 [447-449]. Participant characteristics are presented as arithmetic means and standard deviations (SD). Linear regression models adjusted for sex were used to compare baseline variables between ORI and OSI.

3.2.10.2  **Interactions and Adjustments**
An interaction between sex and obesity resistance/susceptibility (ORS) category was considered for all variables. If a significant interaction between ORS category and sex was identified then the difference between all possible pairs of groups was also examined. It was decided *a priori* to adjust for %BF in order to examine the effect of ORS category on outcomes independent of body composition.

3.2.10.3  **Hormone Concentration and Subjective Appetite Response Analysis**
The fasting and AUC hormone variables were log transformed before analysis and results are presented as medians (interquartile range). Results are presented as differences for sex adjusted for ORS category and differences for ORS category
adjusted for sex from regression analyses. A further adjustment for %BF was conducted by including a term for %BF in the regression model. An interaction between sex and ORS category was considered but as it was not statistically significant it was not included in the final model. No adjustment was made for multiple testing.

### 3.2.10.4 Resting Metabolic Rate (RMR) Analysis

Absolute and relative RMR values are presented as arithmetic means and 95% CI. The estimated difference between ORI and OSI adjusted for sex are also presented as means and 95% CI. Differences for sex adjusted for ORS category and differences for ORS category adjusted for sex were calculated using linear regression.

Estimated RMR, using three prediction equations, was compared to measured RMR using paired t-tests. The proportion of participants whose RMR was predicted to within 10% of the measured RMR was compared using the Chi-square test.

### 3.2.10.5 Dietary Intake Analysis

Regression modelling, controlling for sex was used to assess the relationship between energy (kJ), macro- and micronutrient intakes, and percentage contribution of food group consumption to energy intake and ORS category. A further adjustment for %BF was conducted by including a term for %BF in the regression model for these dietary variables except energy intake relative to BW. Data are presented as arithmetic means and 95% CI with the estimated difference between ORI and OSI also presented as means and 95% CI.

### 3.2.10.6 Physical Activity (PA) and Sedentary Behaviour Analysis

Log transformations were made where this improved residual normality and/or homoscedasticity. Variables which were log transformed are presented as geometric means and 95% CI with differences reported as the percentage difference between the geometric means. The variables which were log transformed were: activity counts, wear time, sedentary, light, moderate and
vigorously movement intensities from accelerometry; and the domain-specific and activity-specific subscales and total PA from the IPAQ. Differences for sex adjusted for ORS category and %BF and differences for ORS category adjusted for sex and %BF were calculated using linear regression.

Data on meeting PA recommendations are presented as frequencies and percentages. Logistic regression models for examining those meeting the recommendations were developed with the goal of limiting the number of predictors to one for each 10 non-events and 10 events using the guidelines from Peduzzi [450]. Therefore only sex was adjusted for in this model.

Regression modeling, controlling for sex, was used to assess the relationship between time spent sitting and ORS category and also to assess the relationship between responses to the attitudes to exercise questionnaire and ORS category. A further adjustment for %BF was conducted by including a term for %BF in the regression model. Time spent sitting data and responses to the attitudes to exercise questionnaire are presented as arithmetic means and 95% CI with the estimated difference between ORI and OSI also presented as means and 95% CI.

Participants were categorized into low, moderate and high levels of PA from the IPAQ. Due to only 1 participant in the low category, low and moderate were combined. Logistic regression was used to estimate the adjusted odds ratio and 95% CIs for PA category. This model was adjusted for ORS category and sex, but not %BF due to insufficient number of events and non-events as per Peduzzi [450].

3.2.10.7 Eating Behaviour Analysis
The TFEQ results are presented as medians in interquartile ranges. The regression model included differences for sex adjusted for ORS category and differences for ORS category adjusted for sex. A further adjustment for %BF was conducted by including a term for %BF in the regression model. An interaction between sex and ORS category was considered but as it was not statistically significant it was not included in the final model. No adjustment was made for multiple testing.
The relationship between ORS category and eating frequency, and time spent eating were assessed using regression modelling, controlling for sex and %BF. Eating indices are presented as means and standard error (SE).
3.3 Results

3.3.1 Participant Characteristics

The characteristics of the B2BL study participants (n=63) are presented in Table 3.7. Obesity resistant individuals (ORI) were significantly lighter, had a lower BMI, LBM, fat mass and %BF, and a smaller WC than obesity susceptible individuals (OSI). There were no differences in age, or height between the two groups and all subjects had a thyroid stimulating hormone (TSH) level within the reference range for adults with no known thyroid dysfunction.

| Table 3.7. Characteristics of obesity resistant individuals (ORI) and obesity susceptible individuals (OSI). |
|--------------------------------------------------|--------------------------------------------------|--------------------------------------------------|------------------|
| **ORI**                                         | **OSI**                                         | **P-value**                                      |
| Females                                        | Males                                          | Females                                        | Males |
| N                                              | 17                                             | 17                                             | 16    | 13 |
| Age (y)                                        | 32.9 (7.5)                                     | 34.6 (7.5)                                     | 35.5 (9.1) | 0.131 |
| BW (kg)                                        | 57.0 (5.9)                                     | 85.5 (15.3)                                    | 94.1 (11.0)     | <0.001 |
| Height (m)                                     | 1.66 (0.06)                                    | 1.66 (0.05)                                    | 1.79 (0.03)    | 0.393 |
| BMI (kg.m⁻²)                                   | 20.7 (1.8)                                     | 31.2 (6.1)                                     | 54.8 (2.9)     | <0.001 |
| WC (cm)                                        | 72.1 (6.2)                                     | 95.0 (10.7)                                    | 99.4 (11.7)    | <0.001 |
| LBM (kg)                                       | 40.3 (4.1)                                     | 45.3 (4.1)                                     | 63.7 (7.6)     | 0.004 |
| Fat Mass (kg)                                  | 13.6 (3.5)                                     | 36.6 (13.9)                                    | 26.1 (8.1)     | <0.001 |
| %BF                                            | 23.9 (5.0)                                     | 41.9 (9.6)                                     | 27.6 (7.1)     | <0.001 |
| TSH (μIU.ml⁻¹)                                 | 1.47 (0.93)                                    | 1.65 (0.74)                                    | 1.58 (0.82)    | 0.998 |

All values are means (SD). *P-values from regression analysis for ORS category adjusted for sex. %BF: percentage body fat, BMI: body mass index, BW: body weight, LBM: lean body mass, ORI: obesity resistant individuals, ORS: obesity resistance/susceptibility, OSI: obesity susceptible individuals, TSH: thyroid stimulating hormone (reference range = 0.3 – 5 μIU.ml⁻¹ for adults with no known thyroid dysfunction), WC: waist circumference.

3.3.2 Hormone Concentrations

Fasting, AUC, peak or nadir, and time to peak or nadir in response to a standardised meal are shown in Table 3.8 for ghrelin, total PYY, leptin, insulin and glucose. Fasting and AUC hormone concentration results have been log transformed. All hormone concentration results are presented as median
Table 3.8. Hormone profiles of obesity resistant individuals (ORI) and obesity susceptible individuals (OSI) in response to a standardised meal

<table>
<thead>
<tr>
<th></th>
<th>ORI</th>
<th></th>
<th>OSI</th>
<th></th>
<th>P-value for sex (adjusted for ORS category)</th>
<th>P-value for ORS category (adjusted for sex)</th>
<th>P-value for ORS category (adjusted for sex and %BF)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ghrelin</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fasting (pg.ml⁻¹)</td>
<td>14</td>
<td>70.7 39.2-129.5</td>
<td>17</td>
<td>55.2 38.6-137.3</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>AUC (mmol.min⁻¹)</td>
<td>11</td>
<td>12596 7470-16987</td>
<td>16</td>
<td>11341 8747-21848</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nadir (pg.ml⁻¹)</td>
<td>16</td>
<td>44.9 31.5-55.3</td>
<td>17</td>
<td>33.7 27.1-56.7</td>
<td></td>
<td></td>
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<tr>
<td>Time to nadir (min)</td>
<td>16</td>
<td>60 30-60</td>
<td>17</td>
<td>60 60-60</td>
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<tr>
<td>Total PYY</td>
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<tr>
<td>Fasting (pg.ml⁻¹)</td>
<td>14</td>
<td>479 40.1-53.7</td>
<td>17</td>
<td>55 47.8-56.3</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>AUC (mmol.min⁻¹)</td>
<td>13</td>
<td>11700 10954-13230</td>
<td>16</td>
<td>12511 10524-13597</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Peak (pg.ml⁻¹)</td>
<td>16</td>
<td>726 68.2-82.0</td>
<td>17</td>
<td>778 66.7-87.5</td>
<td></td>
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<tr>
<td>Time to peak (min)</td>
<td>16</td>
<td>60 45-120</td>
<td>17</td>
<td>60 30-120</td>
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<tr>
<td>Leptin</td>
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<tr>
<td>Fasting (pg.ml⁻¹)</td>
<td>16</td>
<td>2426 1367-3626</td>
<td>17</td>
<td>693.4 4409-1495.0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>AUC (mmol.min⁻¹)</td>
<td>16</td>
<td>425506 231672-582562</td>
<td>16</td>
<td>101878 74897-237294</td>
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<tr>
<td>Nadir (pg.ml⁻¹)</td>
<td>16</td>
<td>2003 1104-2986</td>
<td>17</td>
<td>531.7 3397-1313.4</td>
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<tr>
<td>Time to nadir (min)</td>
<td>16</td>
<td>60 15-120</td>
<td>17</td>
<td>60 30-120</td>
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<td>Insulin</td>
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<tr>
<td>Fasting (pg.ml⁻¹)</td>
<td>13</td>
<td>157 131.1-177.1</td>
<td>15</td>
<td>236.7 110.3-299.6</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>AUC (mmol.min⁻¹)</td>
<td>12</td>
<td>105308 92640-143552</td>
<td>14</td>
<td>139943 109015-171234</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Peak (pg.ml⁻¹)</td>
<td>16</td>
<td>1345.1 965.9-1867.8</td>
<td>17</td>
<td>1677.5 12504-22983</td>
<td></td>
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</tr>
<tr>
<td>Time to peak (min)</td>
<td>16</td>
<td>30 30-30</td>
<td>17</td>
<td>30 30-30</td>
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<tr>
<td>Glucose</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fasting (mmol.l⁻¹)</td>
<td>16</td>
<td>5.3 5.00-5.53</td>
<td>17</td>
<td>5.25 4.95-5.40</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>AUC (mmol.l⁻¹)</td>
<td>16</td>
<td>1030 995-1063</td>
<td>17</td>
<td>1054 1013-1081</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Peak (mmol.l⁻¹)</td>
<td>16</td>
<td>6.9 6.70-7.55</td>
<td>17</td>
<td>7.3 7.00-8.00</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Time to peak (min)</td>
<td>16</td>
<td>15 15-30</td>
<td>17</td>
<td>30 30-30</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Fasting and AUC data have been log transformed, all values are median (interquartile range).

%BF: percentage body fat, AUC: area under the curve, n: number, ORI: obesity resistant individuals, ORS: obesity resistance/susceptibility category, OSI: obesity susceptible individuals, PYY: peptide YY.
(interquartile range) adjusted for obesity resistance/susceptibility (ORS) category and sex with and without adjustment for %BF.

Following adjustment for sex and %BF no differences were observed between ORI and OSI in the analysis of ghrelin, total PYY, leptin, insulin or glucose. A small number of significant differences were observed relating to ORS category before adjustment for %BF. Specifically, a significantly lower fasting leptin concentration, AUC and nadir for leptin, fasting insulin concentration and insulin AUC were seen in ORI versus OSI. However, as previously reported, these differences disappeared when controlling for %BF.

Fasting leptin concentration, AUC and nadir for leptin were all greater in females, while peak glucose was lower in females compared to males. These were the only significant differences observed relating to sex and in all instances these differences became non-significant after further adjustment for %BF.

3.3.3 **Subjective Ratings of Hunger and Satiety**

Fasting, AUC, peak or nadir and time to peak or nadir results for ‘hunger’, ‘desire to eat’, ‘fullness’, and ‘preoccupation with thoughts of food’ in response to a standardised meal are shown in Table 3.9. Subjective ratings of hunger and satiety are presented as median (interquartile range) adjusted for ORS category and sex with and without adjustment for %BF.

No significant differences were observed in fasting, AUC, peak or nadir or time to peak or nadir for the ratings of ‘fullness’ or ‘desire to eat’. The nadir for ‘hunger’ was significantly higher in ORI versus OSI, which suggests participants who struggle to maintain their weight report lower levels of hunger after a standardised meal. A significant sex difference was observed for ‘preoccupation with thoughts of food’, with a higher fasting rating observed in females compared to males and with the nadir occurring significantly later in ORI compared to OSI. However, as with the hormone concentration results, all significant differences in appetite responses disappeared after adjustment for %BF.
Table 3.9. Appetite ratings of obesity resistant individuals (ORI) and obesity susceptible individuals (OSI) in response to a standardised meal

<table>
<thead>
<tr>
<th></th>
<th>ORI</th>
<th></th>
<th>OSI</th>
<th></th>
<th>P-value for sex (adjusted for ORS category)</th>
<th>P-value for ORS category (adjusted for sex)</th>
<th>P-value for ORS category (adjusted for sex and %BF)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Females</td>
<td>Males</td>
<td>Females</td>
<td>Males</td>
<td>P-value for sex (adjusted for ORS category)</td>
<td>P-value for ORS category (adjusted for sex)</td>
<td>P-value for ORS category (adjusted for sex and %BF)</td>
</tr>
<tr>
<td></td>
<td>n Median IQR</td>
<td>n Median IQR</td>
<td>n Median IQR</td>
<td>n Median IQR</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hunger</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fasting (mm)</td>
<td>16 73 55-86</td>
<td>17 67 49-84</td>
<td>15 65 51-77</td>
<td>13 60 40-70</td>
<td>0.515</td>
<td>0.074</td>
<td>0.341</td>
</tr>
<tr>
<td>AUC (mm.min⁻¹)</td>
<td>16 90 40-100</td>
<td>17 64 4200-100</td>
<td>15 42 2790-67</td>
<td>13 61 552-9443</td>
<td>0.506</td>
<td>0.056</td>
<td>0.785</td>
</tr>
<tr>
<td>Nadir (mm)</td>
<td>16 22 2-30</td>
<td>17 19 10-36</td>
<td>15 1 0-4</td>
<td>13 9 1-27</td>
<td>0.170</td>
<td>0.017</td>
<td>0.414</td>
</tr>
<tr>
<td>Time to Nadir (min)</td>
<td>16 15 15-30</td>
<td>17 30 15-60</td>
<td>15 15 15-30</td>
<td>13 15 15-30</td>
<td>0.656</td>
<td>0.305</td>
<td>0.252</td>
</tr>
<tr>
<td>Fullness</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fasting (mm)</td>
<td>15 13 5-29</td>
<td>17 16 6-28</td>
<td>15 14 3-41</td>
<td>13 17 1-28</td>
<td>0.971</td>
<td>0.918</td>
<td>0.826</td>
</tr>
<tr>
<td>AUC (mm.min⁻¹)</td>
<td>15 70 6158-8</td>
<td>17 67 4800-101</td>
<td>15 10 5660-1</td>
<td>13 70 5595-75</td>
<td>0.053</td>
<td>0.451</td>
<td>0.470</td>
</tr>
<tr>
<td>Peak (mm)</td>
<td>16 76 64-95</td>
<td>17 71 49-77</td>
<td>15 90 74-96</td>
<td>13 63 51-77</td>
<td>0.817</td>
<td>0.482</td>
<td>0.754</td>
</tr>
<tr>
<td>Time to peak (min)</td>
<td>16 15 15-30</td>
<td>17 15 15-30</td>
<td>15 15 15-30</td>
<td>13 30 15-30</td>
<td>0.380</td>
<td>0.119</td>
<td>0.860</td>
</tr>
<tr>
<td>Preoccupation with Food</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fasting (mm)</td>
<td>16 63 49-85</td>
<td>17 34 28-63</td>
<td>15 57 30-70</td>
<td>13 41 15-68</td>
<td>0.015</td>
<td>0.441</td>
<td>0.987</td>
</tr>
<tr>
<td>AUC (mm.min⁻¹)</td>
<td>16 60 3173-9</td>
<td>17 46 2805-38</td>
<td>15 28 1875-7</td>
<td>13 66 2378-86</td>
<td>0.446</td>
<td>0.294</td>
<td>0.455</td>
</tr>
<tr>
<td>Nadir (mm)</td>
<td>16 15 4-31</td>
<td>17 10 4-27</td>
<td>15 1 0-4</td>
<td>13 15 1-25</td>
<td>0.309</td>
<td>0.193</td>
<td>0.871</td>
</tr>
<tr>
<td>Time to Nadir (min)</td>
<td>15 15 15-30</td>
<td>17 30 15-30</td>
<td>15 15 15-30</td>
<td>13 15 15-60</td>
<td>0.092</td>
<td>0.040</td>
<td>0.888</td>
</tr>
<tr>
<td>Desire to Eat</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fasting (mm)</td>
<td>16 76 58-85</td>
<td>17 64 45-85</td>
<td>15 69 49-79</td>
<td>13 61 35-72</td>
<td>0.336</td>
<td>0.199</td>
<td>0.243</td>
</tr>
<tr>
<td>AUC (mm.min⁻¹)</td>
<td>16 84 4943-1</td>
<td>17 64 4118-10</td>
<td>15 39 2753-6</td>
<td>13 67 5723-9</td>
<td>0.389</td>
<td>0.148</td>
<td>0.427</td>
</tr>
<tr>
<td>Nadir (mm)</td>
<td>16 25 2-31</td>
<td>17 18 10-31</td>
<td>15 2 0-5</td>
<td>13 15 1-31</td>
<td>0.134</td>
<td>0.059</td>
<td>0.745</td>
</tr>
<tr>
<td>Time to Nadir (min)</td>
<td>16 15 15-30</td>
<td>17 15 15-30</td>
<td>15 15 15-30</td>
<td>13 30 15-60</td>
<td>0.770</td>
<td>0.923</td>
<td>0.940</td>
</tr>
</tbody>
</table>

All values are median (interquartile range)

%BF = percent body fat, AUC = area under the curve, ORI = obesity resistant individuals, ORS = obesity resistance/susceptibility category, OSI = obesity susceptible individuals
3.3.4 Resting Metabolic Rate (RMR)

Results from the resting metabolic rate (RMR) analysis, expressed in absolute terms and relative to BW and fat-free mass (FFM), are presented in Table 3.10. All RMR variables are presented for sex adjusted for ORS category and for ORS category adjusted for sex. When expressed as an absolute value ORI had a significantly lower RMR (748 kJ.d⁻¹, 95%CI: 52, 1443; P=0.036) than OSI as did females compared to males.

Analysis of RMR expressed relative to total BW (kJ.kgBW⁻¹.d⁻¹) revealed OSI had a significantly lower RMR (-15 kJ.kgBW⁻¹.d⁻¹, 95%CI: -24, -6; P=0.001) compared to ORI and that females had a significantly lower RMR than males. An interaction between ORS category and sex was observed for RMR relative to total BW (P=0.023). Pairwise comparisons indicated that female OSI had a significantly lower RMR relative to total BW than all other groups (all P≤0.001). The difference between OSI and ORI females was 25.2 kJ.kg⁻¹.d⁻¹. Given the mean weight of OSI females was 85.5kg this equates to a difference of 2155 kJ.d⁻¹. As opposed to BW adjustment, no differences were observed when RMR was expressed relative to FFM (kJ.kgFFM⁻¹.d⁻¹).

3.3.4.1 Comparison of Measured Resting Metabolic Rate (RMR) with Predicted RMR

The measured RMR of the B2BL cohort (57 participants) was compared to the predicted RMR from three well-known previously published equations (FAO/WHO/UNU, Oxford and Miflin-St Jeor). The mean (95% CI) measured RMR for the B2BL cohort was 6033 (5584, 6483) kJ.d⁻¹. All three equations predicted a significantly higher RMR for the cohort compared to the measured RMR (FAO/WHO/UNU: 7033 (6719, 7348) kJ.d⁻¹, Oxford: 6723 (6407, 7039) kJ.d⁻¹, Miflin-St Jeor: 6691 (6406, 6976) kJ.d⁻¹; all P<0.001).

Table 3.11 shows the results of the comparison of measured RMR with RMR predicted from the FAO/WHO/UNU, Oxford and Miflin-St Jeor equations in obesity resistant and obesity susceptible females and males. All predicted and measured RMR values are presented as means and 95% CI.
Table 3.10. Resting metabolic rate (RMR) of obesity resistant individuals (ORI) and obesity susceptible individuals (OSI)

<table>
<thead>
<tr>
<th></th>
<th>ORI</th>
<th>OSI</th>
<th>Estimated difference estimated difference between ORI and OSI between ORI and OSI adjusted for sex (95%CI)</th>
<th>P-value for sex (adjusted for ORS category)</th>
<th>P-value for sex (adjusted for ORS category)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Females</td>
<td>Males</td>
<td>Females</td>
<td>Males</td>
<td></td>
</tr>
<tr>
<td></td>
<td>n</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>n</td>
<td>14</td>
<td>17</td>
<td>14</td>
<td>12</td>
<td></td>
</tr>
<tr>
<td>Absolute RMR (kJ.day⁻¹)</td>
<td>4878 (4108, 5648)</td>
<td>6518 (5831, 7205)</td>
<td>5072 (4596, 5548)</td>
<td>7817 (7082, 8552)</td>
<td>748 (52, 1443)</td>
</tr>
<tr>
<td>Relative RMR (kJ.kgBW⁻¹.day⁻¹)</td>
<td>86 (74, 98)</td>
<td>88 (80, 96)</td>
<td>61 (53, 68)</td>
<td>83 (78, 89)</td>
<td>-15 (-24, -6)</td>
</tr>
<tr>
<td>Relative RMR (kJ.kgFFM⁻¹.day⁻¹)</td>
<td>123 (107, 139)</td>
<td>112 (101, 122)</td>
<td>111 (101, 121)</td>
<td>123 (113, 133)</td>
<td>0 (-12.4, 12.5)</td>
</tr>
</tbody>
</table>

All values are means (95%CI)
Table 3.11. Comparison of measured resting metabolic rate (RMR) with three previously published equations commonly used to predict RMR in obesity resistant individuals (ORI) and obesity susceptible individuals (OSI)

<table>
<thead>
<tr>
<th></th>
<th>n</th>
<th>Measured RMR (kJ.day(^{-1}))</th>
<th>FAO/WHO/UNU Predicted RMR (kJ.day(^{-1}))</th>
<th>Oxford Predicted RMR (kJ.day(^{-1}))</th>
<th>Miflin-St Jeor Predicted RMR (kJ.day(^{-1}))</th>
<th>P-value (diff between measured and FAO/WHO/UNU)</th>
<th>P-value (diff between measured and Oxford)</th>
<th>P-value (diff between measured and Miflin-St Jeor)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ORI Females</td>
<td>14</td>
<td>4878 (4108, 5648)</td>
<td>5560 (5384, 5737)</td>
<td>5266 (5074, 5457)</td>
<td>5299 (5011, 5587)</td>
<td>0.070</td>
<td>0.269</td>
<td>0.212</td>
</tr>
<tr>
<td>ORI Males</td>
<td>17</td>
<td>6518 (5831, 7205)</td>
<td>7464 (7144, 7785)</td>
<td>7056 (6697, 7415)</td>
<td>7201 (6920, 7482)</td>
<td>0.003</td>
<td>0.063</td>
<td>0.032</td>
</tr>
<tr>
<td>OSI Females</td>
<td>14</td>
<td>5072 (4596, 5548)</td>
<td>6736 (6327, 7144)</td>
<td>6538 (6121, 6955)</td>
<td>6494 (6138, 6850)</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>OSI Males</td>
<td>12</td>
<td>7817 (7082, 8552)</td>
<td>8489 (8088, 8890)</td>
<td>8169 (7688, 8649)</td>
<td>7824 (7435, 8214)</td>
<td>0.030</td>
<td>0.170</td>
<td>0.978</td>
</tr>
</tbody>
</table>

All values are means (95% CI)
All three prediction equations over-estimated RMR to some extent. Specifically, RMR was significantly over-predicted by all three equations for OSI females (1664, 1466 and 1422 kJ.d⁻¹, FAO/WHO/UNU, Oxford and Miflin-St Jeor equations respectively). The estimated RMR of ORI males was over-predicted by the FAO/WHO/UNU equation (946 kJ.d⁻¹) and the Miflin-St Jeor equation (683 kJ.d⁻¹). Only one equation – the FAO/WHO/UNU, over-predicted the RMR of OSI males (672 kJ.d⁻¹), while there was no significant difference in the measured versus predicted RMR for any of the equations for female ORI.

The proportion of obesity resistant and obesity susceptible female and male participants in which RMR was able to be predicted to within 10% of measured RMR by the three prediction equations are presented in Table 3.12. Although the proportion was consistently lower in female OSI for all equations, there was only a statistically significant difference in the Oxford equation where female OSI were lower than male ORI (P=0.002).

3.3.5 Dietary Intake

3.3.5.1 Sensitivity Analysis
The results of the sensitivity analysis revealed that three participants were classified as low energy reporters (LER) determined by having an energy intake to RMR ratio (EI:RMR) of <1.06 [438]. Two LER were obesity susceptible females and one was an obesity resistant female. All dietary analysis was performed on the full sample of 57 participants and repeated with the LER removed (54 participants). As only very minor variations occurred between the two analyses, the results presented in this section are for the full sample of 57 participants. Tables showing the results of the dietary analysis with the LER removed are presented in Appendix N. Any minor variation that has occurred between the two analyses is described below (See section 3.3.5.2, 3.3.5.4 and 3.3.7.2).

3.3.5.2 Energy and Energy-Yielding Nutrient Intake
Table 3.13 shows the results from the four-day weighed diet record (4DDR) analysis for the mean daily intake of energy and the energy-yielding nutrients.
Table 3.12. Proportion of obesity resistant individuals (ORI) and obesity susceptible individuals (OSI) for whom predicted resting metabolic rate (RMR) using three common prediction equations is within 10% of measured RMR

<table>
<thead>
<tr>
<th>Prediction Equation</th>
<th>Females</th>
<th>Males</th>
<th>Females</th>
<th>Males</th>
<th>P-value for ORS category</th>
</tr>
</thead>
<tbody>
<tr>
<td>n</td>
<td>14</td>
<td>17</td>
<td>14</td>
<td>12</td>
<td></td>
</tr>
<tr>
<td>FAO/WHO/UNU</td>
<td>35.7 (5)</td>
<td>41.2 (7)</td>
<td>21.4 (3)</td>
<td>50.0 (6)</td>
<td>0.481</td>
</tr>
<tr>
<td>Oxford</td>
<td>42.9 (6)(^{ab})</td>
<td>76.5 (13)(^a)</td>
<td>21.4 (3)(^b)</td>
<td>50.0 (6)(^{ab})</td>
<td><strong>0.022</strong></td>
</tr>
<tr>
<td>Miflin-St Jeor</td>
<td>35.7 (5)</td>
<td>58.8 (10)</td>
<td>21.4 (3)</td>
<td>66.7 (8)</td>
<td>0.066</td>
</tr>
</tbody>
</table>

All values are mean percentages (n)

When the overall P-values <0.05, pairwise comparisons were performed. Values with different superscript letter indicate significant differences P<0.05

### Table 3.13. Daily energy and energy-yielding nutrient intakes of obesity resistant individuals (ORI) and obesity susceptible individuals (OSI) with* and without adjustment for percentage body fat (%BF)

<table>
<thead>
<tr>
<th>Nutrient</th>
<th>ORI</th>
<th>OSI</th>
<th>ORI</th>
<th>OSI</th>
<th>Estimated difference between ORI and OSI adjusted for sex (95%CI)</th>
<th>P-value for sex (adjusted for ORS category)</th>
<th>Estimated difference between ORI and OSI adjusted for sex (95%CI)</th>
<th>P-value for ORS category (adjusted for sex)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Energy (kJ)</strong></td>
<td>Females: 16</td>
<td>Males: 15</td>
<td>Females: 15</td>
<td>Males: 11</td>
<td>-1054 (-2681, 572)</td>
<td>0.001</td>
<td>906 (-3235, 1423)</td>
<td>0.001</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>-0.199</td>
<td></td>
<td>-906 (-3235, 1423)</td>
<td>0.001</td>
</tr>
<tr>
<td><strong>Energy (kJ.kgBW−1)</strong></td>
<td>Females: 182</td>
<td>Males: 179</td>
<td>Females: 100</td>
<td>Males: 142</td>
<td>-4 (-16, 9)</td>
<td>0.001</td>
<td>2 (-20, 16)</td>
<td>0.001</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>-0.199</td>
<td></td>
<td>-906 (-3235, 1423)</td>
<td>0.001</td>
</tr>
<tr>
<td><strong>Protein (g)</strong></td>
<td>Females: 90</td>
<td>Males: 122</td>
<td>Females: 160</td>
<td>Males: 180</td>
<td>1.2 (-0.3, 2.8)</td>
<td>0.812</td>
<td>1.1 (-1.2, 3.4)</td>
<td>0.937</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>-0.199</td>
<td></td>
<td>-906 (-3235, 1423)</td>
<td>0.001</td>
</tr>
<tr>
<td><strong>Protein (%TEI)</strong></td>
<td>Females: 15.3</td>
<td>Males: 16.6</td>
<td>Females: 15.6</td>
<td>Males: 16.5</td>
<td>0.5 (-3.6, 4.6)</td>
<td>0.936</td>
<td>-4 (-31, 23)</td>
<td>0.005</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>-0.199</td>
<td></td>
<td>-906 (-3235, 1423)</td>
<td>0.001</td>
</tr>
<tr>
<td><strong>Fat (g)</strong></td>
<td>Females: 93</td>
<td>Males: 122</td>
<td>Females: 79</td>
<td>Males: 130</td>
<td>-4 (-31, 23)</td>
<td>0.005</td>
<td>-906 (-3235, 1423)</td>
<td>0.001</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>-0.199</td>
<td></td>
<td>-906 (-3235, 1423)</td>
<td>0.001</td>
</tr>
<tr>
<td><strong>Fat (%TEI)</strong></td>
<td>Females: 32.8</td>
<td>Males: 34.0</td>
<td>Females: 33.4</td>
<td>Males: 33.4</td>
<td>0.5 (-3.6, 4.6)</td>
<td>0.936</td>
<td>-4 (-31, 23)</td>
<td>0.005</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>-0.199</td>
<td></td>
<td>-906 (-3235, 1423)</td>
<td>0.001</td>
</tr>
<tr>
<td><strong>CHO (g)</strong></td>
<td>Females: 315</td>
<td>Males: 322</td>
<td>Females: 232</td>
<td>Males: 361</td>
<td>-60 (-111, -9)</td>
<td>0.001</td>
<td>-906 (-3235, 1423)</td>
<td>0.001</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>-0.199</td>
<td></td>
<td>-906 (-3235, 1423)</td>
<td>0.001</td>
</tr>
<tr>
<td><strong>CHO (%TEI)</strong></td>
<td>Females: 49.0</td>
<td>Males: 44.7</td>
<td>Females: 44.9</td>
<td>Males: 44.9</td>
<td>-3.1 (-7.0, 0.8)</td>
<td>0.001</td>
<td>1.1 (-1.2, 3.4)</td>
<td>0.034</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>-0.199</td>
<td></td>
<td>1.1 (-1.2, 3.4)</td>
<td>0.034</td>
</tr>
<tr>
<td><strong>Alcohol (g)</strong></td>
<td>Females: 4.2</td>
<td>Males: 4.9</td>
<td>Females: 5.4</td>
<td>Males: 3.7</td>
<td>-4 (-31, 23)</td>
<td>0.123</td>
<td>1.1 (-1.2, 3.4)</td>
<td>0.034</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>-0.199</td>
<td></td>
<td>1.1 (-1.2, 3.4)</td>
<td>0.034</td>
</tr>
<tr>
<td><strong>Alcohol (%TEI)</strong></td>
<td>Females: 0.8</td>
<td>Males: 1.2</td>
<td>Females: 1.2</td>
<td>Males: 1.2</td>
<td>-4 (-31, 23)</td>
<td>0.123</td>
<td>1.1 (-1.2, 3.4)</td>
<td>0.034</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>-0.199</td>
<td></td>
<td>1.1 (-1.2, 3.4)</td>
<td>0.034</td>
</tr>
<tr>
<td><strong>Total Sugar (g)</strong></td>
<td>Females: 23.9</td>
<td>Males: 22.9</td>
<td>Females: 19.7</td>
<td>Males: 22.2</td>
<td>-0.9 (-4.0, 2.3)</td>
<td>0.039</td>
<td>1.1 (-1.2, 3.4)</td>
<td>0.034</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>-0.199</td>
<td></td>
<td>1.1 (-1.2, 3.4)</td>
<td>0.034</td>
</tr>
<tr>
<td><strong>Total Sugar (%TEI)</strong></td>
<td>Females: 39.0</td>
<td>Males: 37.5</td>
<td>Females: 29.2</td>
<td>Males: 26.6</td>
<td>-0.9 (-4.0, 2.3)</td>
<td>0.039</td>
<td>1.1 (-1.2, 3.4)</td>
<td>0.034</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>-0.199</td>
<td></td>
<td>1.1 (-1.2, 3.4)</td>
<td>0.034</td>
</tr>
<tr>
<td><strong>SFA (g)</strong></td>
<td>Females: 13.7</td>
<td>Males: 12.6</td>
<td>Females: 12.4</td>
<td>Males: 10.7</td>
<td>-2 (-11.5, 7.5)</td>
<td>0.123</td>
<td>1.1 (-1.2, 3.4)</td>
<td>0.034</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>-0.199</td>
<td></td>
<td>1.1 (-1.2, 3.4)</td>
<td>0.034</td>
</tr>
<tr>
<td><strong>SFA (%TEI)</strong></td>
<td>Females: 31.0</td>
<td>Males: 29.3</td>
<td>Females: 29.5</td>
<td>Males: 41.5</td>
<td>-2 (-11.5, 7.5)</td>
<td>0.123</td>
<td>1.1 (-1.2, 3.4)</td>
<td>0.034</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>-0.199</td>
<td></td>
<td>1.1 (-1.2, 3.4)</td>
<td>0.034</td>
</tr>
<tr>
<td><strong>MUFA (g)</strong></td>
<td>Females: 11.0</td>
<td>Males: 12.8</td>
<td>Females: 10.7</td>
<td>Males: 8.8</td>
<td>-2 (-11.5, 7.5)</td>
<td>0.123</td>
<td>1.1 (-1.2, 3.4)</td>
<td>0.034</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>-0.199</td>
<td></td>
<td>1.1 (-1.2, 3.4)</td>
<td>0.034</td>
</tr>
<tr>
<td><strong>MUFA (%TEI)</strong></td>
<td>Females: 4.9</td>
<td>Males: 4.9</td>
<td>Females: 4.9</td>
<td>Males: 4.9</td>
<td>-2 (-11.5, 7.5)</td>
<td>0.123</td>
<td>1.1 (-1.2, 3.4)</td>
<td>0.034</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>-0.199</td>
<td></td>
<td>1.1 (-1.2, 3.4)</td>
<td>0.034</td>
</tr>
</tbody>
</table>

All values are means (95%CI). *no adjustment for %BF
Daily energy intake is presented in absolute terms (kJ) and relative to BW (kJ.kgBW\(^{-1}\)). Daily intakes of energy-yielding nutrients are presented in absolute terms (g) and as a percentage of total energy intake (TEI). All mean daily intakes and 95% CI are presented. The estimated differences and P-values are presented for sex adjusted for ORS category and for ORS category adjusted for sex. With the exception of daily energy intake expressed relative to BW the regression model has been further adjusted to include %BF.

Surprisingly, there were very few significant differences observed in the intake of energy and energy-yielding nutrients between ORI and OSI both with and without adjustment for %BF. There was no difference in the absolute daily energy intake of ORI compared to OSI. However, when daily energy intake was expressed relative to BW, ORI had a significantly greater intake than OSI. Absolute daily intake of CHO was significantly greater in those resistant compared to those susceptible to obesity, however when adjustment for %BF was included in the regression model, this difference disappeared. When intake of monounsaturated fat (MUFA) as a percentage of TEI was further adjusted for %BF, ORI were observed to have a significantly higher intake compared to OSI. No other differences in the daily intake of energy-yielding nutrients were observed between ORI versus OSI.

As expected, a number of significant differences between females and males were observed in the intake of energy and energy-yielding nutrients. Compared with male participants, females consumed significantly less absolute energy, protein, fat, carbohydrate (CHO) and saturated fat (SFA). Absolute daily intake of MUFA and sugar expressed as a percentage of TEI were significantly greater in females versus males. When intakes were further adjusted for %BF CHO expressed as a percentage of TEI was significantly greater in females versus males and MUFA expressed as a percentage of TEI was significantly less than male participants. No other differences were observed in the daily intake of energy-yielding nutrients or energy relative to BW between females versus males.
An interaction between ORS category and sex was observed for daily protein intake expressed as a percentage of TEI (P=0.035). Pair-wise comparisons indicated that female OSI had a significantly greater intake than female ORI (P=0.034). When LER were removed from the analysis, the interaction remained (P=0.014) and pairwise comparisons again indicated that female OSI had a significantly greater intake of protein expressed as a percentage of TEI than female ORI (P=0.009).

A tendency for an interaction between ORS category and sex was observed for absolute SFA (P=0.053) intake and SFA as a percentage of TEI (P=0.051). When LER were removed from the analysis these interactions became significant (both P=0.050). Pairwise comparisons indicated that female OSI had a significantly lower absolute intake of SFA and SFA as a percentage of TEI than male ORI and male OSI (all P≤0.033).

3.3.5.3 Cholesterol, Fibre and Micronutrient Intake

Results for mean daily intake of cholesterol, fibre and a selection of micronutrients expressed relative to energy intake (g, mg, or μg.1000kJ⁻¹) are presented in Table 3.14. All mean daily intakes and 95% CI are presented. The estimated differences and P-values are presented for sex adjusted for ORS category and for ORS category adjusted for sex. Further adjustment for %BF is also presented. Significantly lower intakes of magnesium and vitamin A relative to energy intake were observed in ORI versus OSI following adjustment for %BF. No differences were observed for cholesterol, fibre, calcium, iron, zinc, thiamin, vitamin C or vitamin E relative to energy intake in ORI compared to OSI.

When %BF was controlled for, the daily intake of calcium and magnesium relative to energy intake was significantly greater in female participants compared to males. No differences were observed between females and males for daily intake of cholesterol, fibre, iron, zinc, thiamin, vitamin A, vitamin C or vitamin E relative to energy intake.
Table 3.14. Daily cholesterol, fibre and selected micronutrient intakes per 1000 kJ of energy intake of obesity resistant individuals (ORI) and obesity susceptible individuals (OSI) with* and without adjustment for percentage body fat (%BF)

<table>
<thead>
<tr>
<th>Nutrient</th>
<th>ORI</th>
<th></th>
<th>OSI</th>
<th></th>
<th>Estimated</th>
<th>P-value for</th>
<th>P-value for</th>
<th>Estimated</th>
<th>P-value for</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Females Males</td>
<td></td>
<td>Females Males</td>
<td></td>
<td>difference</td>
<td>sex (adjusted</td>
<td>ORS category</td>
<td>difference</td>
<td>ORS category</td>
</tr>
<tr>
<td></td>
<td>16 15</td>
<td></td>
<td>15 11</td>
<td></td>
<td>between ORI and</td>
<td>for sex</td>
<td>(adjusted</td>
<td>between ORI and</td>
<td>(adjusted</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>OSI adjusted for</td>
<td>for ORS</td>
<td>for sex</td>
<td>OSI adjusted for</td>
<td>for sex</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>sex (95%CI)</td>
<td>category</td>
<td>(adjusted</td>
<td>sex (95%CI)</td>
<td>(adjusted</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>P-value for</td>
<td>(adjusted</td>
<td>for sex</td>
<td>P-value for</td>
<td>(adjusted</td>
</tr>
<tr>
<td></td>
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<td></td>
<td></td>
<td>sex (adjusted</td>
<td>for ORS</td>
<td>(adjusted</td>
<td>sex (adjusted</td>
<td>for ORS</td>
</tr>
<tr>
<td></td>
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<td></td>
<td></td>
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<td>for ORS category</td>
<td>category</td>
<td>for sex</td>
<td>for ORS category</td>
<td>category</td>
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<td></td>
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<td>sex)</td>
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<td>sex)</td>
<td>for sex</td>
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<tr>
<td>n</td>
<td>16 15</td>
<td></td>
<td>15 11</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cholesterol (mg.1000 kJ⁻¹)</td>
<td>23 (19, 26)</td>
<td>28 (22, 34)</td>
<td>30 (23, 37)</td>
<td>29 (21, 37)</td>
<td>5 (-2, 11)</td>
<td>0.442</td>
<td>0.148</td>
<td>0 (-9, 8)</td>
<td>0.118</td>
</tr>
<tr>
<td>Fibre (g.1000 kJ⁻¹)</td>
<td>3.0 (2.5, 3.5)</td>
<td>2.9 (2.4, 3.4)</td>
<td>3.2 (2.7, 3.7)</td>
<td>2.9 (2.1, 3.7)</td>
<td>0.1 (-0.5, 0.6)</td>
<td>0.490</td>
<td>0.732</td>
<td>0.6 (-0.2, 1.3)</td>
<td>0.103</td>
</tr>
<tr>
<td>Calcium (mg.1000 kJ⁻¹)</td>
<td>112 (93, 130)</td>
<td>101 (85, 117)</td>
<td>128 (100, 156)</td>
<td>94 (75, 114)</td>
<td>6 (-16, 28)</td>
<td>0.054</td>
<td>0.587</td>
<td>21 (-10, 51)</td>
<td>0.019</td>
</tr>
<tr>
<td>Iron (mg.1000 kJ⁻¹)</td>
<td>1.4 (1.2, 1.6)</td>
<td>1.4 (1.2, 1.4)</td>
<td>1.5 (1.4, 1.7)</td>
<td>1.3 (1.1, 1.5)</td>
<td>0 (-0.2, 0.2)</td>
<td>0.318</td>
<td>0.947</td>
<td>0.1 (-0.2, 0.4)</td>
<td>0.224</td>
</tr>
<tr>
<td>Magnesium (mg.1000 kJ⁻¹)</td>
<td>37 (32.41)</td>
<td>38 (32.44)</td>
<td>44 (37.50)</td>
<td>35 (27.43)</td>
<td>2 (-4.8)</td>
<td>0.310</td>
<td>0.450</td>
<td>10 (2.18)</td>
<td>0.013</td>
</tr>
<tr>
<td>Zinc (mg.1000 kJ⁻¹)</td>
<td>1.1 (0.9, 1.2)</td>
<td>1.2 (1.1, 1.4)</td>
<td>1.3 (1.2, 1.4)</td>
<td>1.1 (1.0, 1.2)</td>
<td>0.1 (0.0, 0.2)</td>
<td>0.915</td>
<td>0.191</td>
<td>0.1 (-0.1, 0.3)</td>
<td>0.724</td>
</tr>
<tr>
<td>Thiamin (mg.1000 kJ⁻¹)</td>
<td>0.18 (0.14, 0.23)</td>
<td>0.18 (0.13, 0.23)</td>
<td>0.18 (0.13, 0.23)</td>
<td>0.18 (0.12, 0.23)</td>
<td>0 (-0.5, 0.5)</td>
<td>0.821</td>
<td>0.925</td>
<td>0.03 (-0.04, 0.10)</td>
<td>0.315</td>
</tr>
<tr>
<td>Vitamin A (μg.1000 kJ⁻¹)</td>
<td>10 (82, 125)</td>
<td>92 (66, 119)</td>
<td>126 (94, 158)</td>
<td>121 (74, 168)</td>
<td>26 (-5.56)</td>
<td>0.570</td>
<td>0.103</td>
<td>55 (12.98)</td>
<td>0.099</td>
</tr>
<tr>
<td>Vitamin C (mg.1000 kJ⁻¹)</td>
<td>11 (8, 14)</td>
<td>11 (7, 15)</td>
<td>12 (8.15)</td>
<td>9 (5, 12)</td>
<td>0 (-4.3)</td>
<td>0.508</td>
<td>0.816</td>
<td>2 (-3.7)</td>
<td>0.137</td>
</tr>
<tr>
<td>Vitamin E (mg.1000 kJ⁻¹)</td>
<td>1.1 (0.9, 1.3)</td>
<td>1.1 (0.9, 1.2)</td>
<td>1.2 (1.0, 1.5)</td>
<td>1.0 (0.9, 1.1)</td>
<td>0.1 (-0.1, 0.3)</td>
<td>0.199</td>
<td>0.509</td>
<td>0.1 (-0.2, 0.3)</td>
<td>0.269</td>
</tr>
</tbody>
</table>

All values are means (95%CI)

%BF: percentage body fat, CI: confidence interval, n: number, ORI: obesity resistant individuals, ORS: obesity resistance/susceptibility, OSI: obesity susceptible individuals
An interaction between ORS category and sex was observed for daily intake of magnesium relative to energy intake (P=0.008). Pairwise comparisons indicated that female OSI had a significantly lower intake compared to all other groups (all P<0.001). When LER were removed from the analysis, the interaction remained (P=0.007) and pairwise comparisons again indicated that female OSI had a significantly lower intake of magnesium relative to energy intake compared to all other groups (all P≤0.001).

An interaction between ORS category and sex was also observed for daily intake of zinc relative to energy intake (P=0.003). Pairwise comparisons indicated that female OSI had a significantly greater intake compared to female ORI (P=0.014) and male OSI (P=0.048). Following removal of LER from the analysis, the interaction remained (P=0.002) and again pairwise comparisons indicated that female OSI had a greater intake of zinc relative to energy intake than female ORI (P=0.009) and male OSI (P=0.038).

3.3.5.4 Food Groups

The mean daily percentage contribution to energy intake from 12 different food groups is presented in Table 3.15. Food groups were only included in this analysis if they contributed >3% to TEI. All mean daily percentage contributions and 95% CI are presented. The estimated differences and P-values are presented for sex adjusted for ORS category and for ORS category adjusted for sex. Further adjustment for %BF is also presented.

Few differences were apparent between ORI and OSI. The ‘meat, poultry, fish and seafood’ food group contributed significantly less to TEI for ORI compared to OSI (P=0.037), although, this difference disappeared after controlling for %BF (P=0.515). Conversely, there was a significantly greater contribution to TEI from the ‘cakes, biscuits, puddings, sugar and confectionery’ food group in ORI compared to OSI (although, this difference disappeared after %BF adjustment).

After controlling for %BF, the ‘fruit’ food group made a significantly greater contribution to TEI for female compared to male participants, while the ‘fast foods’ food group made a significantly smaller contribution to TEI in females versus
Table 3.15. Percentage contribution to total energy intake (TEI) from food groups among obesity resistant individuals (ORI) and obesity susceptible individuals (OSI) with* and without adjustment for percentage body fat (%BF)

<table>
<thead>
<tr>
<th>Food Group</th>
<th>ORI Females</th>
<th>ORI Males</th>
<th>OSI Females</th>
<th>OSI Males</th>
<th>Estimated difference between ORI and OSI adjusted for sex (95% CI)</th>
<th>P-value for sex (adjusted for ORS category)</th>
<th>P-value for ORS category (adjusted for sex)</th>
<th>*Estimated difference between ORI and OSI adjusted for sex (95% CI)</th>
<th>*P-value for sex (adjusted for ORS category)</th>
<th>*P-value for ORS category (adjusted for sex)</th>
</tr>
</thead>
<tbody>
<tr>
<td>n</td>
<td>16</td>
<td>15</td>
<td>15</td>
<td>11</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bread, grains, pasta, cereals &amp; breakfast cereals</td>
<td>22.2 (18.6, 25.9)</td>
<td>25.3 (20.6, 30.0)</td>
<td>19.9 (16.1, 23.7)</td>
<td>24.3 (18.8, 29.9)</td>
<td>-1.7 (-6.1, 2.6)</td>
<td>0.094</td>
<td>0.426</td>
<td>-3.4 (-6.5, 5.8)</td>
<td>0.356</td>
<td>0.908</td>
</tr>
<tr>
<td>Fruit</td>
<td>6.7 (4.3, 9.0)</td>
<td>6.4 (4.2, 8.7)</td>
<td>6.5 (4.2, 8.8)</td>
<td>4.4 (1.1, 17.7)</td>
<td>-1.0 (-3.5, 1.5)</td>
<td>0.393</td>
<td>0.426</td>
<td>-1.0 (-3.5, 1.5)</td>
<td>0.009</td>
<td>0.108</td>
</tr>
<tr>
<td>Vegetables</td>
<td>3.7 (2.2, 5.6)</td>
<td>2.3 (1.3, 3.4)</td>
<td>4.2 (2.7, 5.7)</td>
<td>3.1 (1.1, 5.0)</td>
<td>0.6 (-0.9, 2.1)</td>
<td>0.096</td>
<td>0.443</td>
<td>1.4 (-0.8, 3.5)</td>
<td>0.052</td>
<td>0.199</td>
</tr>
<tr>
<td>Milk, cheese &amp; dairy products</td>
<td>14.5 (11.3, 17.7)</td>
<td>10.9 (7.6, 14.1)</td>
<td>14.9 (11.2, 18.5)</td>
<td>11.6 (6.3, 16.8)</td>
<td>0.5 (-3.2, 4.2)</td>
<td>0.068</td>
<td>0.781</td>
<td>2.2 (-3.1, 7.5)</td>
<td>0.050</td>
<td>0.415</td>
</tr>
<tr>
<td>Butter, margarine, fats &amp; oils</td>
<td>4.9 (3.4, 6.3)</td>
<td>4.0 (1.8, 6.1)</td>
<td>4.3 (2.3, 6.2)</td>
<td>5.5 (1.6, 9.4)</td>
<td>0.4 (-1.9, 2.7)</td>
<td>0.953</td>
<td>0.747</td>
<td>-2.2 (-5.4, 1.0)</td>
<td>0.143</td>
<td>0.169</td>
</tr>
<tr>
<td>Meat, poultry, fish &amp; seafood</td>
<td>7.6 (5.3, 10.0)</td>
<td>8.8 (6.4, 11.1)</td>
<td>11.7 (8.3, 15.1)</td>
<td>10.9 (6.8, 15.0)</td>
<td>3.2 (0.2, 6.2)</td>
<td>0.872</td>
<td>0.037</td>
<td>1.4 (-2.8, 5.6)</td>
<td>0.381</td>
<td>0.515</td>
</tr>
<tr>
<td>Sausages &amp; processed meat</td>
<td>2.5 (0.3, 4.6)</td>
<td>2.8 (1.2, 4.4)</td>
<td>1.8 (0.5, 3.2)</td>
<td>4.1 (1.6, 6.5)</td>
<td>0.2 (-1.7, 2.0)</td>
<td>0.209</td>
<td>0.848</td>
<td>-1.2 (-3.8, 1.4)</td>
<td>0.058</td>
<td>0.385</td>
</tr>
<tr>
<td>Cakes, biscuits, puddings, sugar &amp; confectionery</td>
<td>18.3 (13.1, 23.5)</td>
<td>13.4 (6.4, 20.3)</td>
<td>9.2 (5.5, 12.8)</td>
<td>9.8 (4.7, 14.9)</td>
<td>-6.6 (-12.1, -1.1)</td>
<td>0.379</td>
<td>0.019</td>
<td>-6.3 (-14.2, 1.5)</td>
<td>0.460</td>
<td>0.110</td>
</tr>
<tr>
<td>Nuts &amp; seeds</td>
<td>3.5 (0.5, 6.4)</td>
<td>2.6 (0.7, 4.4)</td>
<td>3.1 (1.5, 4.7)</td>
<td>0.8 (0.0, 2.0)</td>
<td>-0.4 (-3.3, 2.6)</td>
<td>0.162</td>
<td>0.356</td>
<td>-3.4 (-3.4, 2.7)</td>
<td>0.148</td>
<td>0.816</td>
</tr>
<tr>
<td>Snack foods</td>
<td>3.0 (1.4, 4.5)</td>
<td>3.2 (1.3, 5.0)</td>
<td>4.5 (0.3, 8.6)</td>
<td>1.9 (0.0, 4.0)</td>
<td>0.2 (-2.4, 2.9)</td>
<td>0.439</td>
<td>0.857</td>
<td>1.2 (-2.6, 5.0)</td>
<td>0.299</td>
<td>0.531</td>
</tr>
<tr>
<td>Fast Foods</td>
<td>2.1 (0.5, 3.6)</td>
<td>8.9 (3.3, 14.5)</td>
<td>6.1 (3.7, 8.5)</td>
<td>6.2 (1.5, 10.8)</td>
<td>1.0 (-2.9, 4.8)</td>
<td>0.053</td>
<td>0.617</td>
<td>-1.6 (-7.1, 3.8)</td>
<td>0.020</td>
<td>0.553</td>
</tr>
<tr>
<td>Juice &amp; sweetened beverages</td>
<td>3.5 (1.5, 5.2)</td>
<td>2.9 (1.8, 4.0)</td>
<td>2.9 (1.4, 4.8)</td>
<td>4.5 (2.1, 6.8)</td>
<td>0.5 (-1.3, 2.3)</td>
<td>0.635</td>
<td>0.609</td>
<td>0.5 (-2.1, 3.1)</td>
<td>0.730</td>
<td>0.703</td>
</tr>
</tbody>
</table>

All values are means (95% CI)  
Additional food groups were removed from analysis if they contributed < 3%TEI (eggs; hot beverages & water; meat alternatives; savoury sauces & spreads; potato, kamara & taro)  
%BF: percentage body fat; CI: confidence interval; n: number, ORI: obesity resistant individuals, ORS: obesity resistance/susceptibility, OSI: obesity susceptible individuals, TEI: total energy intake
males. The ‘milk, cheese and dairy products’ food group also made a significantly greater contribution to TEI for females compared to males, however, when LER were removed from the analysis this difference became non-significant (P=0.067). By contrast, with the removal of LER from the analysis, the tendency (P=0.052) for a greater contribution from the ‘vegetables’ food group to TEI in females compared to males became significantly different (P=0.045). No further differences in the percentage contribution of food groups to TEI were observed between female and male participants.

No interactions between ORS category and sex were observed in the percentage contribution of food groups to TEI.

3.3.6  Physical Activity (PA) and Sedentary Behaviour
All PA and sedentary behaviour variables obtained from analysis of the accelerometer data and the IPAQ, with the exception of the IPAQ sitting and level of PA data and the exercise attitude and motivations questionnaire data, have been log-transformed. Geometric means and 95%CI are presented. The estimated differences (reported as the percentage difference between geometric means) and P-values are presented for sex adjusted for ORS category and for ORS category adjusted for sex. Further adjustment for %BF is also presented.

3.3.6.1  Accelerometry Data
Mean activity counts per minute and mean daily accelerometer wear time for ORI compared to OSI are presented in Table 3.16. Participants generated between 224 (female OSI) and 301 (male ORI) activity counts per minute (cpm) on average. Mean accelerometer wear time ranged from 14.8 (male OSI) to 15.2 (male ORI) hours per day. No differences were observed for either variable between ORI and OSI or between female and male participants.

3.3.6.1.1  Level of Movement Intensity
The mean amount of time participants spent participating in various levels of movement intensity are also presented in Table 3.16. Participants spent between
Table 3.16. Mean activity counts, daily wear time and amount of time spent in various levels of movement intensity of obesity resistant individuals (ORI) and obesity susceptible individuals (OSI) measured using accelerometry with* and without adjustment for percentage body fat (%BF)

<table>
<thead>
<tr>
<th></th>
<th>ORI</th>
<th></th>
<th>OSI</th>
<th></th>
<th>Percentage difference between ORI and OSI adjusted for sex</th>
<th>P-value for ORS category adjusted for sex</th>
<th>*Percentage difference between ORI and OSI adjusted for sex</th>
<th>*P-value for ORS category adjusted for sex</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Females</td>
<td>Males</td>
<td>Females</td>
<td>Males</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>n</td>
<td>12</td>
<td>17</td>
<td>14</td>
<td>11</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Activity Counts (cpm)</td>
<td>273 (196, 380)</td>
<td>301 (224, 404)</td>
<td>224 (159, 315)</td>
<td>259 (172, 390)</td>
<td>-16.0</td>
<td>0.444</td>
<td>0.272</td>
<td>23.2</td>
</tr>
<tr>
<td>Wear Time (h.d⁻¹)</td>
<td>15.0 (14.3, 15.7)</td>
<td>15.2 (14.6, 15.8)</td>
<td>14.9 (14.0, 15.9)</td>
<td>14.8 (13.9, 15.8)</td>
<td>-1.6</td>
<td>0.887</td>
<td>0.518</td>
<td>0.8</td>
</tr>
<tr>
<td>Sedentary (h.d⁻¹)</td>
<td>10.7 (9.7, 11.8)</td>
<td>10.8 (9.9, 11.8)</td>
<td>10.9 (10.0, 12.0)</td>
<td>10.4 (9.4, 11.6)</td>
<td>-0.7</td>
<td>0.717</td>
<td>0.866</td>
<td>-3.6</td>
</tr>
<tr>
<td>Light (h.d⁻¹)</td>
<td>3.3 (2.7, 4.0)</td>
<td>2.8 (2.3, 3.5)</td>
<td>3.0 (2.4, 3.8)</td>
<td>3.3 (2.7, 3.9)</td>
<td>2.3</td>
<td>0.752</td>
<td>0.810</td>
<td>15.1</td>
</tr>
<tr>
<td>Moderate (h.d⁻¹)</td>
<td>0.46 (0.32, 0.69)</td>
<td>0.66 (0.43, 1.00)</td>
<td>0.46 (0.35, 0.60)</td>
<td>0.59 (0.39, 0.88)</td>
<td>-5.7</td>
<td>0.101</td>
<td>0.743</td>
<td>16.8</td>
</tr>
<tr>
<td>Vigorous (h.d⁻¹)</td>
<td>0.16 (0.07, 0.39)</td>
<td>0.12 (0.05, 0.28)</td>
<td>0.05 (0.01, 0.17)</td>
<td>0.02 (0.01, 0.09)</td>
<td>-76.0</td>
<td>0.344</td>
<td><strong>0.006</strong></td>
<td>21.5</td>
</tr>
</tbody>
</table>

All variables were log transformed and geometric means (95%CI) are presented with differences reported as the percentage difference between geometric means. %BF: percentage body fat, cpm: counts per minute, n: number, ORI: obesity resistant individuals, ORS: obesity resistance/susceptibility, OSI: obesity susceptible individuals.
10.4 (male OSI) and 10.9 (female OSI) hours per day engaged in sedentary behaviours and between 2.8 (male ORI) and 3.3 (female ORI, male OSI) hours per day performing light intensity activities. Considerably less time was spent engaging in moderate intensity activities (<1 hour per day for all groups) with only 1.2 (male OSI) to 9.6 (female ORI) minutes per day being spent engaged in vigorous intensity activities. No differences were observed in the amount of time spent engaging in sedentary behaviours or performing light or moderate intensity activities in ORI compared to OSI. The amount of time spent performing vigorous intensity activities was observed to be greater in ORI versus OSI (P=0.006), however, this difference disappeared following adjustment for %BF (P=0.777).

No differences were observed between females and males for the amount of time spent engaging in sedentary behaviours or performing light or moderate intensity activities. After controlling for %BF, the amount time spent performing vigorous intensity level activity was significantly greater in female participants compared to males (9.6, 7.2, 3.0, 1.2 min.d⁻¹, ORI females, ORI males, OSI females, OSI males respectively; P=0.008).

No interactions between ORS category and sex were observed in activity counts, wear-time or level of movement intensity.

3.3.6.1.2 Adherence to Physical Activity (PA) Recommendations
Data obtained from accelerometry was used to examine the adherence to PA recommendations in two ways:

1) A weekly sum of 150 or more minutes of a combination of MVPA per week (7 days) accumulated in bouts of at least 10 min.

2) Probability of accumulating at least 30 min of MVPA in bouts of at least 10 min on at least 5 days of the week (ie 5 out of 7 days).

The proportion of ORI and OSI accumulating at least 150 min of MVPA per week is shown in Figure 3.4. The majority of participants were meeting this recommendation (83% obesity resistant females, 71% obesity resistant males, 64% obesity susceptible females and 91% obesity susceptible males). No
Figure 3.4. Proportion of obesity resistant individuals (ORI) and obesity susceptible individuals (OSI) accumulating ≥150 min of moderate- to vigorous-intensity physical activity (MVPA) per week.

Figure 3.5. Proportion of obesity resistant individuals (ORI) and obesity susceptible individuals (OSI) accumulating ≥30 min of moderate- to vigorous-intensity physical activity (MVPA) ≥5 days per week.
differences in adherence to this PA recommendation were observed between ORI and OSI (P=0.879) or between female and male participants (P=0.510).

The proportion of ORI and OSI achieving the more stringent recommendation of accumulating at least 30 min of MVPA on at least 5 days per week is presented in Figure 3.5. Fifty percent of obesity resistance females, 53% of obesity resistant males, 43% of obesity susceptible females and 45% of obesity susceptible males were meeting this recommendation. Again no differences were observed between ORI and OSI (P=0.571) or between female and male participants (P=0.781) in adherence to this PA recommendation.

3.3.6.2 International Physical Activity Questionnaire (IPAQ)

3.3.6.2.1 Domain-Specific Physical Activity (PA) Subscales
Physical activity (PA) measured in four domain-specific subscales (work-related PA, transport-related PA, domestic and garden activities and leisure-time PA) is presented in Table 3.17. Participants were only included in the work-related PA domain if they responded with a ‘yes’ to the question “Do you currently have a job or do any unpaid work outside the home?”. No differences in PA between ORI and OSI were observed for any of the domain-specific subscales. Female participants performed significantly less work-related PA than male participants, however, this difference disappeared following adjustment for %BF. No differences were observed between males and females for transport-related PA, domestic and garden activities or leisure-time PA. No interactions between ORS category and sex were observed for any of the domain-specific subscales.

3.3.6.2.2 Activity-Specific Subscales
Table 3.17 shows PA measured in three activity-specific subscales (walking, moderate-intensity and vigorous-intensity). After controlling for %BF, ORI reportedly performed significantly less vigorous-intensity PA than their OSI counterparts. There were no differences in walking or moderate-intensity PA observed between ORI versus OSI or females versus males. Vigorous-intensity PA appeared to be performed significantly less by female participants compared to
Table 3.17. Physical activity (PA) performed in various domains assessed by the International Physical Activity Questionnaire (IPAQ) among obesity resistant individuals (ORI) and obesity susceptible individuals (OSI) with* and without adjustment for percentage body fat (%BF)

<table>
<thead>
<tr>
<th>Domain-Specific Subscales</th>
<th>ORI</th>
<th>OSI</th>
<th>Percentage difference between ORI and OSI adjusted for sex</th>
<th>P-value for ORS category (adjusted for sex)</th>
<th>Percentile difference between ORI and OSI adjusted for sex</th>
<th>P-value for ORS category (adjusted for sex)</th>
</tr>
</thead>
<tbody>
<tr>
<td>n</td>
<td>17</td>
<td>16</td>
<td>Females</td>
<td></td>
<td>Males</td>
<td></td>
</tr>
<tr>
<td>Work-related (MET-min.wk⁻¹)</td>
<td>1072 (722, 2129)</td>
<td>2173 (795, 5936)</td>
<td>725 (342, 1638)</td>
<td>891 (1169, 9164)</td>
<td>15.0</td>
<td>0.012</td>
</tr>
<tr>
<td>Transport-related (MET-min.wk⁻¹)</td>
<td>503 (255, 994)</td>
<td>484 (195, 1201)</td>
<td>332 (119, 929)</td>
<td>202 (71, 574)</td>
<td>-42.7</td>
<td>0.561</td>
</tr>
<tr>
<td>Domestic &amp; Garden Activities (MET-min.wk⁻¹)</td>
<td>427 (165, 1101)</td>
<td>280 (135, 615)</td>
<td>444 (203, 971)</td>
<td>596 (214, 1659)</td>
<td>45.1</td>
<td>0.839</td>
</tr>
<tr>
<td>Leisure-Time (MET-min.wk⁻¹)</td>
<td>625 (333, 1172)</td>
<td>986 (512, 1899)</td>
<td>892 (368, 2161)</td>
<td>720 (284, 1823)</td>
<td>3.2</td>
<td>0.663</td>
</tr>
<tr>
<td>Activity-Specific Subscales</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Walking (MET-min.wk⁻¹)</td>
<td>1267 (765, 2101)</td>
<td>1252 (743, 2108)</td>
<td>1240 (603, 2155)</td>
<td>612 (216, 1736)</td>
<td>-33.0</td>
<td>0.361</td>
</tr>
<tr>
<td>Moderate Intensity (MET-min.wk⁻¹)</td>
<td>1150 (619, 2167)</td>
<td>1201 (616, 2341)</td>
<td>920 (460, 1837)</td>
<td>2199 (1013, 4773)</td>
<td>18.9</td>
<td>0.205</td>
</tr>
<tr>
<td>Vigorous intensity (MET-min.wk⁻¹)</td>
<td>374 (220, 635)</td>
<td>908 (405, 2034)</td>
<td>592 (291, 1204)</td>
<td>1104 (415, 2941)</td>
<td>39.4</td>
<td>0.031</td>
</tr>
<tr>
<td>Total Physical Activity (MET-min.wk⁻¹)</td>
<td>3219 (2057, 5038)</td>
<td>4434 (2717, 7237)</td>
<td>3420 (2019, 5793)</td>
<td>6293 (3961, 10159)</td>
<td>22.2</td>
<td>0.049</td>
</tr>
</tbody>
</table>

All variables were log transformed and geometric means (95%CI) are presented with differences reported as the percentage difference between geometric means
* = participant numbers differ from full IPAQ sample (ORI females n=8, ORI males n=10, OSI females n=8, OSI males n=9)
%BF: percentage body fat, IPAQ: International Physical Activity Questionnaire, n: number, ORI: obesity resistant individuals, ORS: obesity resistance/susceptibility, OSI: obesity susceptible individuals
male participants, but this difference was no longer significant after adjustment for %BF. No interactions were observed between ORS category and sex for any of the activity-specific subscales.

3.3.6.2.3 Total Physical Activity (PA)
Total PA as measured by the IPAQ is presented in Table 3.17. After adjustment for %BF, ORI reported significantly lower total PA compared to OSI. Female participants appeared to have a lower total PA compared to male participants, however, after controlling for %BF this difference no longer remained significant. No interactions were observed between ORS category and sex for total PA.

3.3.6.2.4 Sitting
The total weekly and mean daily time spent sitting both with and without the inclusion of time spent sitting while travelling in a motor vehicle are presented in Table 3.18. All mean daily and weekly times and 95% CI are presented. The estimated differences and P-values are presented for sex adjusted for ORS category and for ORS category adjusted for sex. Further adjustment for %BF is also presented. No differences in any of the sitting variables were observed between ORI and OSI or between female and male participants. In addition, no interactions were observed between ORS category and sex for any of the sitting variables.

3.3.6.2.5 Level of Physical Activity (PA)
As a consequence of only one participant being classified into the ‘Low’ category of PA, the ‘Low’ and ‘Moderate’ categories were combined to form the ‘Low-to-Moderate’ PA category for this analysis. The proportion of ORI and OSI classified according to the IPAQ as performing a low-to-moderate versus a high level of PA is presented in Figure 3.6. The majority of participants were classified into the ‘High’ PA category (53% obesity resistant females, 75% obesity resistant males, 71% obesity susceptible females and 77% obesity susceptible males). No differences in the proportion of participants classified into the ‘High’ versus ‘Low-to-Moderate’ PA categories were observed between ORI and OSI (P=0.381) or between females and males (P=0.225).
Table 3.18. Total weekly and mean daily time spent sitting assessed by the International Physical Activity Questionnaire (IPAQ) among obesity resistant individuals (ORI) and obesity susceptible individuals (OSI) with* and without adjustment for percentage body fat (%BF)

<table>
<thead>
<tr>
<th></th>
<th>ORI</th>
<th></th>
<th>OSI</th>
<th></th>
<th>Estimated difference between ORI and OSI adjusted for sex (95%CI)</th>
<th>P-value for sex (adjusted for ORS category)</th>
<th>P-value for sex (adjusted for ORS category)</th>
<th>Estimated difference between ORI and OSI adjusted for sex (95%CI)</th>
<th>P-value for sex (adjusted for ORS category)</th>
<th>P-value for sex (adjusted for ORS category)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Females Males</td>
<td>Females Males</td>
<td>Females Males</td>
<td>Females Males</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>n</td>
<td>16 14</td>
<td>13 12</td>
<td>13 12</td>
<td>16 14</td>
<td>0.563 0.435 54 (-763, 871) 0.918 0.895</td>
<td>0.928 0.268 35 (-87, 157) 0.910 0.567</td>
<td>0.928 0.268 35 (-87, 157) 0.910 0.567</td>
<td>0.928 0.268 35 (-87, 157) 0.910 0.567</td>
<td>0.928 0.268 35 (-87, 157) 0.910 0.567</td>
<td>0.928 0.268 35 (-87, 157) 0.910 0.567</td>
</tr>
<tr>
<td>Sitting (min.wk⁻¹)</td>
<td>2492 (1952, 3032) 2799 (2188, 3409)</td>
<td>315 (2658, 3772) 2478 (1717, 3238)</td>
<td>228 (-354, 810)</td>
<td>0.563 0.435 54 (-763, 871) 0.918 0.895</td>
<td>0.928 0.268 35 (-87, 157) 0.910 0.567</td>
<td>0.928 0.268 35 (-87, 157) 0.910 0.567</td>
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<td>0.928 0.268 35 (-87, 157) 0.910 0.567</td>
</tr>
<tr>
<td>Sitting (min.d⁻¹)</td>
<td>356 (279, 433) 400 (3131, 487)</td>
<td>459 (380, 539) 354 (245, 462)</td>
<td>33 (-51, 116)</td>
<td>0.562 0.435 54 (-763, 871) 0.918 0.895</td>
<td>0.928 0.268 35 (-87, 157) 0.910 0.567</td>
<td>0.928 0.268 35 (-87, 157) 0.910 0.567</td>
<td>0.928 0.268 35 (-87, 157) 0.910 0.567</td>
<td>0.928 0.268 35 (-87, 157) 0.910 0.567</td>
<td>0.928 0.268 35 (-87, 157) 0.910 0.567</td>
<td>0.928 0.268 35 (-87, 157) 0.910 0.567</td>
</tr>
<tr>
<td>Sitting including Transport (min.wk⁻¹)</td>
<td>2865 (2377, 3352) 3078 (2390, 3767)</td>
<td>3453 (2815, 4090) 3138 (2304, 3973)</td>
<td>338 (-266, 942)</td>
<td>0.930 0.267 245 (-606, 1096) 0.909 0.566</td>
<td>0.928 0.268 35 (-87, 157) 0.910 0.567</td>
<td>0.928 0.268 35 (-87, 157) 0.910 0.567</td>
<td>0.928 0.268 35 (-87, 157) 0.910 0.567</td>
<td>0.928 0.268 35 (-87, 157) 0.910 0.567</td>
<td>0.928 0.268 35 (-87, 157) 0.910 0.567</td>
<td>0.928 0.268 35 (-87, 157) 0.910 0.567</td>
</tr>
<tr>
<td>Sitting including Transport (min.d⁻¹)</td>
<td>409 (340, 479) 440 (341, 538)</td>
<td>493 (402, 584) 448 (329, 567)</td>
<td>48 (-38, 135)</td>
<td>0.928 0.268 35 (-87, 157) 0.910 0.567</td>
<td>0.928 0.268 35 (-87, 157) 0.910 0.567</td>
<td>0.928 0.268 35 (-87, 157) 0.910 0.567</td>
<td>0.928 0.268 35 (-87, 157) 0.910 0.567</td>
<td>0.928 0.268 35 (-87, 157) 0.910 0.567</td>
<td>0.928 0.268 35 (-87, 157) 0.910 0.567</td>
<td>0.928 0.268 35 (-87, 157) 0.910 0.567</td>
</tr>
</tbody>
</table>

All values are means (95%CI)

* = Total sitting time plus time spent sitting while travelling in a motor vehicle e.g. train, bus, car etc

%BF: percentage body fat, IPAQ: International Physical Activity Questionnaire, n: number, ORI: obesity resistant individuals, ORS: obesity resistance/susceptibility, OSI: obesity susceptible individuals
Figure 3.6. Proportion of obesity resistant individuals (ORI) and obesity susceptible individuals (OSI) classified according to the International Physical Activity Questionnaire (IPAQ) performing a low-to-moderate level versus a high level of physical activity (PA)
3.3.6.3 Attitudes to Exercise
Results of the questionnaire assessing attitudes and motivations relating to exercise are presented in Table 3.19. Mean responses and 95% CI are presented. The estimated differences and P-values are presented for sex adjusted for ORS category and for ORS category adjusted for sex. Further adjustment for %BF is also presented.

Obesity resistant individuals (ORI) were more likely to disagree with the statement ‘After an exercise session I feel thinner’ than OSI. However, this difference disappeared after adjustment for %BF. After controlling for sex and %BF, individuals who appear resistant to obesity were more likely to agree with the statement ‘I am a sporting type of person’ than individuals susceptible to obesity. In addition, ORI were more likely to disagree with the statements: ‘The rest of my life has to fit around my exercise’, and ‘If I do not exercise I feel I cannot cope with everyday life’ compared to OSI. Conversely, obesity susceptible individuals (OSI) were more likely to agree with the statements: ‘I hate not being able to exercise’ and ‘I exercise to control my weight’ compared to individuals resistant to obesity.

Only one significant sex difference in response to the questionnaire was observed. In the fully adjusted model, female participants were more likely to disagree with the statement ‘I only exercise to maintain a healthy BW, but I don’t really enjoy it’ compared to males. No interactions were observed between ORS category and sex for any of the responses to the statements assessing exercise attitudes and motivations.

3.3.7 Eating Behaviour
3.3.7.1 Dietary Restraint, Disinhibition and Hunger
Results from the three-factor eating questionnaire (TFEQ) are shown in Figure 3.7 (presented as medians in interquartile ranges). Dietary restraint and disinhibition scores were significantly lower in ORI compared to OSI (both P<0.001), and remained statistically lower even after adjustment for %BF (P<0.001 and P=0.005,
Table 3.19. Attitudes and motivations relating to exercise among obesity resistant individuals (ORI) and obesity susceptible individuals (OSI) with* and without adjustment for percentage body fat (%BF)

<table>
<thead>
<tr>
<th>Statement</th>
<th>ORI Females</th>
<th>ORI Males</th>
<th>OSI Females</th>
<th>OSI Males</th>
<th>Estimated difference between ORI and OSI</th>
<th>ORI P-value for sex (adjusted for ORS category)</th>
<th>OSI P-value for sex (adjusted for ORS category)</th>
<th>Estimated difference between ORI and OSI</th>
<th>OSI P-value for sex (adjusted for ORS category)</th>
<th>ORI P-value for ORS category (adjusted for sex)</th>
<th>OSI P-value for ORS category (adjusted for sex)</th>
</tr>
</thead>
<tbody>
<tr>
<td>After an exercise session I feel happier about life</td>
<td>4.1 (3.7, 4.6)</td>
<td>4.4 (4.0, 4.7)</td>
<td>4.5 (4.2, 4.9)</td>
<td>4.3 (3.9, 4.6)</td>
<td>0.2 (-0.2, 0.5)</td>
<td>0.969</td>
<td>0.362</td>
<td>0.3 (-0.2, 0.9)</td>
<td>0.677</td>
<td>0.245</td>
<td></td>
</tr>
<tr>
<td>If I cannot exercise I feel irritable</td>
<td>3.2 (2.4, 3.8)</td>
<td>3.3 (2.7, 3.9)</td>
<td>3.3 (2.8, 3.8)</td>
<td>3.3 (2.4, 4.1)</td>
<td>0.1 (-0.5, 0.7)</td>
<td>0.757</td>
<td>0.686</td>
<td>0.7 (-0.2, 1.6)</td>
<td>0.460</td>
<td>0.148</td>
<td></td>
</tr>
<tr>
<td>The rest of my life has to fit in around my exercise</td>
<td>2.2 (1.6, 2.9)</td>
<td>2.6 (2.1, 3.1)</td>
<td>2.3 (1.5, 3.0)</td>
<td>2.9 (2.0, 3.8)</td>
<td>0.2 (-0.5, 0.8)</td>
<td>0.135</td>
<td>0.596</td>
<td>1.0 (0.1, 1.9)</td>
<td>0.823</td>
<td>0.037</td>
<td></td>
</tr>
<tr>
<td>After an exercise session I feel less stressed</td>
<td>4.2 (3.8, 4.6)</td>
<td>3.8 (3.4, 4.2)</td>
<td>4.1 (3.6, 4.5)</td>
<td>4.3 (3.9, 4.6)</td>
<td>0.1 (-0.2, 0.5)</td>
<td>0.549</td>
<td>0.471</td>
<td>0.2 (-0.3, 0.8)</td>
<td>0.445</td>
<td>0.403</td>
<td></td>
</tr>
<tr>
<td>If I cannot exercise I feel frustrated</td>
<td>2.9 (2.3, 3.6)</td>
<td>3.4 (2.7, 4.0)</td>
<td>3.3 (2.8, 3.8)</td>
<td>3.4 (2.6, 4.2)</td>
<td>0.2 (-0.4, 0.8)</td>
<td>0.344</td>
<td>0.496</td>
<td>0.6 (0.3, 1.5)</td>
<td>0.991</td>
<td>0.168</td>
<td></td>
</tr>
<tr>
<td>I hate not being able to exercise</td>
<td>3.2 (2.5, 3.9)</td>
<td>3.4 (2.7, 4.0)</td>
<td>3.6 (3.0, 4.2)</td>
<td>3.6 (2.8, 4.3)</td>
<td>0.3 (-0.3, 0.9)</td>
<td>0.765</td>
<td>0.375</td>
<td>1.1 (0.2, 2.0)</td>
<td>0.179</td>
<td>0.013</td>
<td></td>
</tr>
<tr>
<td>If I do not exercise I feel I cannot cope with everyday life</td>
<td>2.1 (1.5, 2.7)</td>
<td>1.8 (1.4, 2.2)</td>
<td>2.3 (1,7, 2.8)</td>
<td>2.8 (1.8, 3.7)</td>
<td>0.5 (-0.1, 1.1)</td>
<td>0.870</td>
<td>0.083</td>
<td>1.0 (0.2, 1.9)</td>
<td>0.355</td>
<td>0.016</td>
<td></td>
</tr>
<tr>
<td>I exercise to control my weight</td>
<td>2.5 (1.8, 3.1)</td>
<td>2.1 (1.4, 2.7)</td>
<td>3.9 (3.6, 4.3)</td>
<td>3.8 (3.2, 4.4)</td>
<td>1.6 (1,1, 2.2)</td>
<td>0.313</td>
<td>0.001</td>
<td>1.3 (0.5, 2.1)</td>
<td>0.883</td>
<td>0.002</td>
<td></td>
</tr>
<tr>
<td>I exercise to be healthy</td>
<td>4.3 (3.8, 4.7)</td>
<td>4.4 (4.0, 4.7)</td>
<td>4.5 (4.1, 4.8)</td>
<td>4.0 (3.5, 4.5)</td>
<td>-0.1 (-0.4, 0.3)</td>
<td>0.436</td>
<td>0.780</td>
<td>0 (-0.6, 0.6)</td>
<td>0.438</td>
<td>0.992</td>
<td></td>
</tr>
<tr>
<td>After an exercise session I feel thinner</td>
<td>2.5 (1.9, 3.1)</td>
<td>2.5 (2.0, 3.1)</td>
<td>3.2 (2.5, 3.9)</td>
<td>3.2 (2.6, 3.8)</td>
<td>0.7 (0.1, 1.2)</td>
<td>0.959</td>
<td>0.027</td>
<td>0.6 (0.3, 1.4)</td>
<td>0.907</td>
<td>0.186</td>
<td></td>
</tr>
<tr>
<td>After an exercise session I feel more positive about myself</td>
<td>3.9 (3.4, 4.4)</td>
<td>4.1 (3.7, 4.4)</td>
<td>4.3 (3.9, 4.6)</td>
<td>4.1 (3.9, 4.3)</td>
<td>0.2 (-0.1, 0.6)</td>
<td>0.917</td>
<td>0.226</td>
<td>0.2 (-0.3, 0.7)</td>
<td>0.926</td>
<td>0.422</td>
<td></td>
</tr>
<tr>
<td>I exercise to feel fit</td>
<td>4.2 (3.8, 4.6)</td>
<td>4.2 (4.0, 4.5)</td>
<td>4.4 (4.0, 4.8)</td>
<td>4.0 (3.6, 4.4)</td>
<td>0 (-0.3, 0.3)</td>
<td>0.367</td>
<td>0.997</td>
<td>0.1 (0,4, 0.6)</td>
<td>0.315</td>
<td>0.723</td>
<td></td>
</tr>
<tr>
<td>I only exercise to maintain a healthy body weight, but don't really enjoy it</td>
<td>1.8 (1,3, 2.2)</td>
<td>2.1 (1.5, 2.6)</td>
<td>2.2 (1.6, 2.8)</td>
<td>2.2 (1.3, 3.0)</td>
<td>0.3 (-0.3, 0.8)</td>
<td>0.596</td>
<td>0.306</td>
<td>0.6 (-1.4, 1.1)</td>
<td>0.017</td>
<td>0.110</td>
<td></td>
</tr>
<tr>
<td>I feel uncomfortable when I exercise so I try to avoid it</td>
<td>1.8 (1.3, 2.3)</td>
<td>1.5 (1.2, 1.9)</td>
<td>2.0 (1.4, 2.6)</td>
<td>2.1 (1.3, 2.8)</td>
<td>0.4 (-0.1, 0.9)</td>
<td>0.638</td>
<td>0.159</td>
<td>0 (-0.8, 0.7)</td>
<td>0.599</td>
<td>0.924</td>
<td></td>
</tr>
<tr>
<td>If I cannot exercise I feel horrible</td>
<td>2.8 (2.2, 3.4)</td>
<td>2.8 (2.2, 3.4)</td>
<td>2.9 (2.3, 3.4)</td>
<td>3.2 (2.2, 4.2)</td>
<td>0.2 (-0.4, 0.8)</td>
<td>0.672</td>
<td>0.558</td>
<td>0.7 (-0.2, 1.6)</td>
<td>0.511</td>
<td>0.115</td>
<td></td>
</tr>
<tr>
<td>After an exercise session I feel less anxious</td>
<td>3.4 (2.8, 4.0)</td>
<td>3.6 (3.1, 4.0)</td>
<td>3.4 (2.7, 4.1)</td>
<td>3.9 (3.4, 4.4)</td>
<td>0.1 (-0.4, 0.7)</td>
<td>0.248</td>
<td>0.613</td>
<td>0.3 (0.5, 1.1)</td>
<td>0.602</td>
<td>0.426</td>
<td></td>
</tr>
<tr>
<td>I am a sporty-type of person</td>
<td>3.3 (2.5, 4.1)</td>
<td>3.5 (2.9, 4.1)</td>
<td>2.8 (1.9, 3.7)</td>
<td>3.4 (2.7, 4.1)</td>
<td>-0.3 (-1.0, 0.4)</td>
<td>0.341</td>
<td>0.379</td>
<td>1.0 (0,1, 1.9)</td>
<td>0.127</td>
<td>0.037</td>
<td></td>
</tr>
</tbody>
</table>

All values are means (95% CI)  
%BF: percentage body fat, CI: confidence interval, n: number, ORI: obesity resistant individuals, ORS: obesity resistance/susceptibility, OSI: obesity susceptible individuals
dietary restraint and disinhibition scores, respectively). By contrast, indications for hunger did not differ between those resistant and susceptible to obesity with (P=0.665) and without (P=0.749) adjustment for %BF. Interestingly, sex did not influence scores for dietary restraint, disinhibition or hunger.

![Figure 3.7](image.png)

**Figure 3.7.** Three-factor eating questionnaire (TFEQ) scores for obesity resistant (OR) females (F) and males (M) versus obesity susceptible (OS) females (F) and males (M). Values are medians in 25th and 75th interquartile range. * = obesity resistant individuals (ORI) < obesity susceptible individuals (OSI) P≤0.005.

### 3.3.7.2 Eating Frequency

The results for the mean number of daily eating occasions are presented in Figure 3.8. Participants reported between 3.8 (male OSI) and 5.2 (female ORI) eating occasions per day on average. The number of daily eating occasions was observed to be greater in ORI compared to OSI (P=0.026), however, this difference disappeared following adjustment for %BF (P=0.602). In addition, after controlling for %BF, a significantly greater number of eating occasions per day was observed in females compared to males (P=0.029). When LER were removed from
Figure 3.8. Eating frequency of obesity resistant individuals (ORI) and obesity susceptible individuals (OSI). Values are means ± SE. P-value adjusted for percentage body fat (%BF). * indicates females > males (P=0.029)

Figure 3.9. Total time spent eating of obesity resistant individuals (ORI) and obesity susceptible individuals (OSI). Values are means ± SE.
the analysis, this difference no longer remained significant (P=0.051). No interactions between ORS category and sex were observed in eating frequency.

3.3.7.3 Time Spent Eating

Figure 3.9 shows the results for the mean amount of time spent eating per day. Participants reported spending between 94 min (female ORI) and 105 min (male ORI) eating per day. No differences were observed between ORI and OSI or between female and male participants with and without adjustment for %BF. No interactions between ORS category and sex were observed in the amount of time spent eating per day.
3.4 Discussion

Why some individuals remain lean with relative ease while others continuously struggle with their BW, despite living in a similar environment, is an intriguing question. At present, the area of obesity resistant research in humans is restricted to a small number of studies, using varied definitions of resistance and susceptibility to obesity and investigating a limited range of variables. The aim of the present study was to compare and contrast the characteristics of individuals who are seemingly resistant to obesity (ORI) to those who struggle to maintain a healthy BW (OSI).

The results of the B2BL study indicate there are some measurable differences in the characteristics of ORI compared to OSI, especially with regard to RMR, attitudes towards exercise and eating behaviour. Specifically, the absolute RMR (kJ.d⁻¹) was lower in ORI versus OSI, while RMR relative to BW (kJ.kg⁻¹.d⁻¹) was higher in ORI, with female OSI displaying the lowest RMR relative to BW compared to all other groups. The three selected RMR prediction equations all over-predicted the RMR of female OSI, whereas only some equations over-predicted the RMR of males in either group and none of the equations over-predicted the RMR of female ORI. Differences between the ORS categories were observed in response to a number of statements in the attitudes to exercise questionnaire. Most notably, OSI were more likely to agree with the statement ‘I exercise to control my weight’ than ORI, while ORI were more likely to agree with the statement ‘I am a sporty person’. Finally, restrained eating and disinhibition, as measured by the TFEQ, were significantly lower in ORI compared to OSI.

While some differences were found in the characteristics of ORI compared to OSI, there were also a number of variables for which unexpectedly, no differences between the two ORS categories were observed. This includes the majority of measurements relating to fasting and post-prandial hormone concentrations and appetite responses, dietary intake, physical activity and sedentary behaviour.
3.4.1 Hormone Concentrations and Appetite Responses

One of the reasons why individuals differ in their susceptibility to weight gain may be due to physiological differences in appetite control. In the current study the ghrelin, total peptide YY (PYY), leptin and appetite responses to a standard meal were studied in ORI compared to OSI. Interestingly, despite some differences in absolute values of these hormones, the pattern of change in response to a standard meal was very similar between both groups.

3.4.1.1 Hormone Concentrations

Ghrelin, an orexigenic hormone, is acutely negatively regulated by the ingestion of meals [91, 92]. Therefore as anticipated, the concentrations of ghrelin decreased in both ORI and OSI upon feeding reaching a nadir between 30 and 60 min. Ghrelin is positively regulated by fluxes in overall energy balance [91, 451]. A number of previous studies have shown that obese individuals tend to have lower fasting ghrelin levels compared to lean controls ie ghrelin is negatively correlated with %BF [452-455]. Based on these observations and the differences in body composition between the two groups, one may have expected ORI to have a higher fasting ghrelin compared to OSI. However, the present study showed no differences in ghrelin concentration both before and after adjustment for %BF.

The lack of difference in ghrelin concentrations between ORI and OSI may indicate two different mechanisms. While the OSI ghrelin levels are due to increased energy stores, the lower than predicted ghrelin levels in ORI may be due to a possible underlying mechanism which theoretically provides protection against overeating and subsequent weight gain. As a result, no obvious differences are apparent between the two groups. Obesity resistant individuals (ORI) differ from other populations that have been investigated previously in that rather than simply being lean they also largely struggle to gain weight (84% of ORI responded positively to the screening tool statement “I am a person who finds it difficult to put on weight”). Germain and colleagues [38] investigated constitutionally thin individuals (CTI) (a group that finds it difficult to gain weight) and also found lower than expected fasting ghrelin concentrations given the low %BF of CTI.
participants. As ghrelin is orexigenic this finding may indicate a possible mechanism that prevents these particularly lean individuals from overeating.

A limitation associated with the interpretation of the ghrelin results in the present study is that ghrelin concentrations differ throughout the day in cyclic fashion in relation to meal taking and diurnal rhythms [91]. By assessing values over a 4 h period in the morning, it may be that the analyses were simply unable to capture differences in ghrelin levels. Germain and colleagues [38] measured the 24 hour ghrelin profiles of CTI compared to normal weight, age-matched controls and observed lower ghrelin concentrations in the CTI.

Peptide YY (PYY) is an anorexigenic hormone associated with meal satiety and therefore theoretically meal termination [456, 457]. The majority of previous studies investigating overweight and/or obese compared to lean subjects have reported higher postprandial PYY levels amongst lean individuals [454, 458-460]. As such, one may anticipate that those who remain lean with relative ease (ORI) would have a correspondingly higher concentration of PYY in response to feeding compared with those who struggle to maintain a healthy BW (OSI). However, no differences in PYY concentrations in response to a meal were found between the groups in the present study. This finding compliments the ghrelin results, perhaps also indicating a differential response to the same PYY level in ORI compared to OSI. To the candidate’s knowledge, PYY concentrations in response to a single standardised meal have not been assessed by any study within the obesity resistance literature.

In the present study, the fasting and postprandial leptin concentrations were higher in the group with the greater BMI (OSI), which is consistent with results from previous studies where higher leptin concentrations have been associated with higher levels of BMI/body fat [110, 453, 461]. Similar results for fasting leptin levels have also been reported within the obesity resistance literature when comparing CTI with normal weight controls [25, 27], lean with reduced obese participants [29, 30] and obesity resistant with obesity susceptible participants [28]. These results are in line with previous literature that has highlighted the
concept of leptin resistance in overweight and obese individuals as a result of increased adipose stores [106]. With no adjustment for BMI or %BF in these studies it is to difficult to ascertain whether the higher concentration of leptin in obesity susceptible participants reflects leptin resistance or is just a marker of greater adipose tissue mass in this group. In the present study the differences in fasting and postprandial leptin concentrations between ORI compared to OSI disappeared after controlling for %BF. The potential implication is that the initial differences were an artifact of disparities in body composition rather than inherent differences in leptin concentration between the two groups.

3.4.1.2 Appetite Responses

As with the analysis of hormone concentrations in the present study, any differences in perceived appetite ratings between the obesity resistant and obesity susceptible participants disappeared following adjustment for %BF. However, prior to this adjustment, the most notable finding was ORI appeared to experience smaller fluctuations in hunger ratings. In addition, despite OSI having markedly higher leptin concentrations than ORI, the scores for perceived satiety were equivalent, suggesting OSI may not be fully responding to the high concentrations of leptin. A limited number of studies in the obesity resistance literature have assessed hunger and satiety responses and reported no differences between participants representing obesity resistant versus obesity susceptible individuals [31, 34, 81]. However, the participants in all of these studies followed a prescribed eucaloric diet for 4-6 days prior to the assessment of appetite responses which may have produced different responses compared to an ad libitum diet.

In the present study the energy content of the standardised meal was based on sex rather than estimated energy requirements. This method of assigning energy content could have potentially resulted in the OSI and ORI eating more or less than they are used to. Further, given the similar hormone patterns and appetite responses it would have been interesting to observe how much our two groups would have eaten when presented with an ad libitum meal following the 4 h testing procedures. Would they choose a similar meal size or would the OSI have actually
wanted to eat more? This more realistic eating situation could form part of future research investigating obesity resistance.

In summary, the finding of a similar ghrelin concentration, despite differential BW in the two study groups observed in the present study was unexpected. As the present study was powered to detect a 5% difference in ghrelin concentration the reason no difference was observed in ORI versus OSI is unlikely to be due to a lack of power. The results could indicate that OSI respond differently to the same ghrelin concentration or conversely, the lower than expected fasting ghrelin levels observed in the ORI may provide a protective mechanism that enables these individuals to remain lean. Further investigation of these possibilities in more realistic eating settings is warranted.

### 3.4.2 Resting Metabolic Rate

Resting metabolic rate (RMR) accounts for around 60-75% of total daily energy expenditure [127]. As such variations in or modifications of RMR have the potential to influence energy balance and conceivably one’s susceptibility to gaining or maintaining BW.

#### 3.4.2.1 Measured Resting Metabolic Rate (RMR)

In the present study, indirect calorimetry was used to measure the RMR of individuals who maintain their BW with relative ease (ORI) compared to individuals who struggle to maintain a healthy BW (OSI). Differences in both absolute and relative measures of RMR were observed between the two study groups. The absolute measured RMR was significantly higher in OSI compared to ORI, which corresponds with previous research in obese versus lean participants [132-136]. This finding was not unexpected given the differences in body composition between the two groups (significantly higher BW, LBM and fat mass in OSI). In addition, male participants had a significantly higher absolute RMR than females - another predictable finding related to sex differences in BW and body composition.
To account for the effect of body composition on RMR, both within and between individuals, an adjustment for FFM has often been performed as FFM is considered the most metabolically active body tissue. In the present study when RMR was expressed relative to FFM no differences were observed between ORI and OSI. This is in line with previous research in lean versus obese participants [135].

However, recent evidence shows that organs such as the brain, heart, liver and kidneys as well as fat and skeletal muscle mass contribute significantly to resting energy expenditure [138], thus total BW has been shown to be better correlated with RMR than FFM alone in individuals with a high BMI [139, 140]. Some of the most interesting findings from the present study relate to the comparison of RMR expressed relative to total BW in obesity resistant and obesity susceptible participants. Significant differences were observed between males and females (males higher), and between ORI and OSI (ORI = 15 kJ.kg\(^{-1}\).d\(^{-1}\) higher). Most notably, female OSI were observed to have a lower RMR relative to total BW than all other groups.

The difference between OSI females (a group that finds it difficult to maintain a healthy BW) and ORI females (a group that finds it easy to maintain a healthy BW) was 25.2 kJ.kg\(^{-1}\).d\(^{-1}\). While this might appear small on a daily basis, over time, if compensatory behaviours such as reducing energy intake or increasing energy expenditure were not initiated, this disparity in RMR could lead to significant increases in BW. Predicted weight gain is estimated to be up to 10.4 kg over a 12 month period according to the Pennington Biomedical Research Center calculator [462] which uses a dynamic human weight change prediction model developed by Thomas and colleagues [463]. Interestingly, 100% of female OSI indicated positively to the screening statement: “I need to consume small amounts to manage my weight” (Table 3.2). This suggests that the female OSI in the present study are somehow aware of their potentially reduced metabolic rate, or at least their propensity to gain weight, and attempt to compensate for this to some extent by consuming less.
By definition, OSI (individuals who struggle to maintain a healthy BW) are likely to have gained and lost weight in the past. This was corroborated by OSI responses to the weight history questions asked as part of the B2BL study questionnaire. This may be one explanation for the differences in RMR between the two groups in the present study. Previous research suggests RMR is suppressed in conjunction with weight loss, often to a greater extent than would be expected based on changes in BW/ body composition [141-143]. Arguably the most successful dieters on the planet, competitors in ‘The Biggest Loser™’ television programme with the greatest weight loss at the end of the competition also experienced the greatest slowing of RMR [143]. Those who were most successful at maintaining weight loss after 6 years experienced the greatest metabolic slowing, despite continuing to engage in high levels of exercise [142]. In addition, metabolic suppression persisted even in those who experienced substantial weight regain in the intervening 6 year period [142]. Therefore, due to potential past fluctuations in BW, the OSI (especially the females) in the present study may be exhibiting metabolic adaptation – an adaptive response that reduces energy expenditure to oppose the maintenance of a reduced BW [144, 145].

Comparison of the RMR results of the present study with previous obesity resistance research is difficult for a number of reasons. Firstly, in all the studies where a comparison of RMR values has been undertaken [25, 28, 30, 31, 77] the sample size is very small (7 – 13 participants in each group) which may impact on their ability to detect small differences in RMR due to a lack of statistical power. Secondly, sex influences RMR, mainly due to differences in body composition. In the two studies that included both males and females within the obesity resistant and susceptible groups [30, 31], no adjustment for sex was undertaken to account for differences in BW, FFM and fat mass. Finally, the groups have been variably defined within these studies as CTI versus normal BW [25, 77], lean/thin versus reduced obese [30, 31] and obesity resistant versus obesity susceptible [28]. Taking into consideration the impact of body composition on RMR and the likelihood that body composition will vary depending on the definition of the study groups, the ability to compare the results from these studies with the present study is hampered.
A limitation of the present study is that with 57 participants distributed across four groups, participant matching by age, physical activity or other lifestyle factors was not possible. Resting metabolic rate (RMR) is affected by age and decreases 1-2% per decade after 20 years of age [464]. Participants were accepted into the present study if they were aged between 20 and 45 years and although the mean age and range in each group were similar, participants could have been more evenly matched to reduce the effects of age on RMR. The RMR of individuals who exercise regularly is generally found to be higher than non-exercisers [465] and in particular, resistance training has an impact on RMR due to its role in increasing FFM [465, 466]. Although physical activity levels were similar between ORI and OSI in the present study (see section 3.3.6), the methods used to assess physical activity did not provide specific information on engagement in resistance exercise and it is therefore unknown to what degree differences in resistance exercise participation may have had on RMR.

### 3.4.2.2 Predicted Resting Metabolic Rate (RMR)

The finding of a difference in RMR between ORI and OSI has some important implications. Measurement of an individual’s RMR in a clinical setting is often not feasible due to constraints relating to cost, equipment, time and personnel [128, 146, 147]. Instead predictive equations are commonly used in dietetic practice to estimate the energy needs of an individual as part of a complete nutritional assessment. Predicted RMR calculated using three well-known equations was compared to the measured RMR of ORI compared to OSI.

The finding that all three of the prediction equations over-estimated RMR to some extent was not all-together surprising. Of the numerous RMR prediction equations that have been published to date, there is considerable debate regarding which is the best for predicting RMR in any particular setting and especially in overweight and obese individuals [128, 131, 146-148, 155]. The fact the three prediction equations struggled to predict RMR to within 10% of measured RMR for the majority of participants (Table 3.12) provides an indication of the extent of the disparity between the predicted and measured RMR values.
The difference between measured and predicted RMR was most apparent in the OSI female study group, with all three of the prediction equations significantly over-estimating RMR. This finding has some important implications for dietetic practice. The Oxford equation has recently been adopted by Dietitians New Zealand and is recommended for calculating BMR in the latest edition of the Clinical Handbook [149]. Meanwhile, the Academy of Nutrition and Dietetics (formally the American Dietetic Association) recommends using the Miflin-St Jeor equation for estimating RMR in overweight and obese individuals [150]. As these equations overestimate RMR in this group of women who struggle with maintaining a healthy BW, their use in dietary counseling is likely to lead to an over-prediction of total energy requirements. Therefore, calculation of energy restriction based on these over-predicted energy requirements may be insufficient to facilitate meaningful weight maintenance/loss in this group, leading to disappointment and anxiety as clients/patients fail to meet their healthy BW targets. In addition, the Miflin-St Jeor equation is used to estimate RMR and from there to predict energy requirements as part of the self-monitoring dietary intake app ‘MyFitnessPal™’ [467], as such, the energy requirements for weight loss of any OSI females using this app are likely to be overestimated. With reportedly 80 million users worldwide [468] including, undoubtedly, a fair proportion who could be defined as female OSI, there are potentially numerous users who may be wondering why they are unable to achieve the weight loss targets predicted by the app.

In summary metabolic adaptation, as evidenced by a low RMR relative to BW, may be present in women who identify as needing to consume smaller amounts to manage their weight (OSI). Further, commonly used prediction equations used to estimate RMR are likely to over-estimate total energy requirements. This could be an issue for users of self-monitoring dietary intake apps and websites as a potential reason for failure to meet the predicted weight loss targets. Women, are more likely to seek nutrition counseling than men [469, 470], therefore asking clients/patients to complete the simple screening tool used in the present study could help identify obesity susceptible women and allow dietary counselors to
factor in a potentially lower energy requirement than may be predicted from RMR
equations, prior to planned energy restriction.

3.4.3    Dietary Intake
A number of dietary factors have been linked to promoting or protecting against
the development of obesity including energy intake, intake of individual
macronutrients and their constituents and the intake of certain foods or food
groups. In the present study, a 4DDR was used to assess the dietary intake of ORI
compared to OSI. Surprisingly, very few significant differences were observed in
any of the dietary variables investigated in the present study.

3.4.3.1    Energy and Energy-Yielding Nutrients
Absolute daily energy intake of ORI compared to OSI was not significantly different.
This is consistent with the small number of studies in the obesity resistance
literature that have also reported no significant difference in energy intake (kJ.d⁻¹)
in female CTI compared to normal weight controls [25, 38, 77] or obesity resistant
versus obesity susceptible males with a high fat intake [28]. However, the finding
of a significantly lower intake of energy relative to BW in OSI compared ORI raises
a number of questions:
1) Are the OSI actually consuming smaller amounts relative to their BW?
or
2) Are the OSI consuming smaller amounts because the recording process is
making them aware of what they are eating? (ie undereating)
or
3) Is the lower relative energy intake in OSI due to underreporting?

Firstly, it is difficult to separate whether the finding of a lower relative energy
intake in OSI compared to ORI is associated with questions 1 or 2 or both. In the
present study, OSI indicated the need to consume smaller amounts to manage their
weight (100% of OSI females; 64% of OSI males) (Table 3.2) based on their
response to the screening tool statements and as evidenced by a lower RMR
relative to BW compared to ORI. Taken together, the lower relative energy intake
combined with evidence of a lower relative RMR could represent confirmation of this subjective perception in OSI. Equally the behaviour of both the obesity susceptible and obesity resistant participants may have been altered by the burden of the recording process to the extent that they consumed less [438, 471-473].

Underreporting of energy intake is a common source of measurement error in dietary assessment [226, 227, 438]. A number of characteristics of underreporters have been identified [227] including weight status and behavioural effects that may have relevance to the present study. Dietary restraint has been linked with energy underreporting [473, 474]. In the present study, dietary restraint was significantly higher in the obesity susceptible compared to the obesity resistant participants (see section 3.3.7.1). Weight status has also been related to low energy reporting with the probability that an individual will underreport generally increasing as BMI increases [227, 475-477]. Body mass index (BMI) in the present study was also significantly higher in OSI compared to ORI. Therefore, based on the characteristics of the obesity susceptible participants there was potential for low energy reporting to be occurring which could explain the lower relative energy intake in OSI versus ORI.

Low energy reporting was assessed in the present study using measured RMR and applying appropriate Goldberg cut-off values [438]. In studies where dietary intake misreporting has been identified, the magnitude of underreporting of energy intake is often around 30% of participants [226]. In the present study only 3 of the 57 participants included in the dietary analysis were classified as LER by having an EI:RMR of <1.06. Removal of these 3 participants from the analysis did not affect the group energy intake results. In addition, an analysis of energy intakes using the appropriate cut-off values for the four sex and ORS category groups [438], indicated low energy reporting was not occurring at the group level (cut-off = 1.38-1.42; ORI F = 2.11; ORI M = 2.06; OSI F = 1.65; OSI M = 1.71). Based on these results it appears low energy reporting is unlikely to be responsible for the lower relative energy intake of OSI compared to ORI in the present study.
Dietary fat, CHO, protein and alcohol have all received some attention with respect to the potentially positive or negative effect consumption of these nutrients may have on the development of obesity. Various macronutrient distributions have been used in diets designed to prevent and treat obesity including low fat, high CHO; low CHO, high fat; and high protein models [478-480]. However, results from a systematic review examining the role of dietary macronutrient composition and changes in weight suggest the proportion of macronutrients in the diet is not important in the prevention of obesity [479]. Interestingly, in the present study, the macronutrient distribution patterns were remarkably similar between the obesity resistant and obesity susceptible participants, which is consistent with the small number of studies where dietary intake has been assessed within the obesity resistance literature [25, 28, 38, 77]. In addition the macronutrient distribution patterns for both the obesity resistant and obesity susceptible groups fit within the Acceptable Macronutrient Distribution Ranges (AMDR) for macronutrients to reduce chronic disease for the New Zealand population of 15-25% TEI from protein, 20-35% TEI from fat and 45-65% TEI from CHO [481].

3.4.3.2 Food Groups

The associations between foods and dietary patterns and weight gain appear to be stronger compared to those between macronutrient distribution and weight gain [479]. However, in the present study there were again remarkable similarities between ORI and OSI in terms of the intake of various different food groups as a proportion of energy intake. Unfortunately a sample size of 57 precluded any further in depth analysis of dietary patterns for comparison in the two study populations. It also appears no other research within the obesity resistance literature has compared the intake of specific foods, food groups or dietary patterns in individuals resistant or susceptible to obesity.

In summary, there is evidence that energy intake relative to BW is lower in individuals susceptible to obesity compared to those who appear resistant to obesity. This finding does not appear to be the result of low energy reporting, but is consistent with OSI self-report that they need to consume less to manage their weight. However, it must be acknowledged that diet records only provide a
‘snapshot’ of dietary intake. Measuring the nutrient and food intake over a limited period may fail to capture broader dietary habits that are related to the longer-term development of obesity.

3.4.4 Physical Activity (PA) and Sedentary Behaviour

Decreased PA and/or increased time spent engaging in sedentary behaviours have the potential to reduce total energy expenditure and have, therefore, been linked to development of the obesity epidemic. In the present study, PA levels, adherence to PA recommendations and sedentary behaviour were assessed in ORI and compared to OSI using both objective (accelerometry) and subjective (IPAQ) measures. As with the dietary intake outcomes, there were very few significant differences observed using either method for any of the PA variables or sedentary behaviours investigated in the present study.

3.4.4.1 Level of Movement Intensity

Accelerometry data indicated there were no significant differences in the amount of time spent performing light, moderate, or vigorous PA in ORI compared to OSI. No significant differences between obesity resistant and obesity susceptible participants were also observed for the amount of walking, moderate PA and for the domain-specific subscales assessed by the IPAQ. These findings are consistent with previously reported results in the obesity resistance literature, where no differences were observed in the activity-induced energy expenditure (AEE) of female CTI compared to normal weight controls [25, 77] or in the mean number of steps per day assessed over 1 week in obesity resistant versus obesity prone individuals [82].

In contrast, according to results obtained from the IPAQ, OSI report undertaking a significantly greater amount (MET.min⁻¹.wk⁻¹) of vigorous and total PA compared to ORI. The somewhat disparate results obtained from the IPAQ compared to the accelerometry data may be partially explained by the subjective versus objective nature of the methods selected to assess PA in the present study. Self-reported physical activity questionnaires (SRPAQ), such as IPAQ, are prone to measurement
error and bias associated with cognitive limitations related to recall of the activity and actual comprehension of the questionnaire [296, 297]. As a consequence, most researchers agree that SRPAQ are less accurate than objective measures, such as accelerometry, for estimating MVPA and PA energy expenditure [284, 286, 294]. In addition, the IPAQ was developed for use in surveillance studies [288, 295], therefore, the relatively small sample size of the present study (n=60) may be have been too small to effectively use the IPAQ in this population.

3.4.4.2 Activity Counts
The accelerometry data indicated the activity counts per minute of obesity resistant participants were 23.2% greater than obesity susceptible participants. This difference was not statistically significant, possibly due to the reasonably small sample size (n=54) as indicated by the relatively wide confidence intervals. However, this finding may still have clinical significance. Over time the difference in activity counts could result in differences in total energy expenditure and therefore the ability to prevent weight gain in those susceptible to obesity compared to those resistant to obesity.

3.4.4.3 Sedentary Behaviour
Increased time spent engaging in sedentary pursuits is likely to increase the risk of weight gain by decreasing total energy expenditure. In the present study no significant differences were observed in the amount of time spent sitting (IPAQ) or in the amount of time spent engaging in sedentary behaviours (accelerometry) between ORI and OSI. In addition to evidence of a strong relationship between sedentary behaviour, all-cause mortality and numerous non-communicable diseases (NCD) [273], sedentary behaviour has also been associated with a greater consumption of energy-dense snacks and sugar-sweetened (SS) beverages and reduced intake of fruit and vegetables in young people [276, 277]. In the present study, consistent with the findings for sedentary behaviour, no significant differences were observed in the intake of ‘cakes, biscuits, puddings, sugar and confectionery’, ‘snack foods’, ‘fast foods’ or ‘juice and sweetened beverages’ between ORI and OSI.
Interestingly, both obesity resistant and obesity susceptible participants in the present study spent 70 – 73% of their waking time while wearing an accelerometer engaged in sedentary behaviours (sedentary h.d\(^{-1}\) divided by wear time h.d\(^{-1}\)). For both ORS categories, this equates to a considerable amount of time every day. Previous research has demonstrated a positive effect of breaks in sedentary time on measures of WC and BMI [283]. Therefore, recommendations that target sedentary behaviour may be of merit to assist with weight control.

### 3.4.4.4 Attitudes to Exercise and Adherence to Physical Activity (PA) Recommendations

There is evidence of a difference in attitudes towards exercise amongst ORI compared to OSI. Perhaps not surprisingly, individuals susceptible to obesity were more likely to agree with the statement ‘I exercise to control my weight’ than individuals resistant to obesity. This finding is interesting when viewed alongside the results from the analyses of adherence to PA recommendations. No significant differences were observed in the proportion of OSI versus ORI classified as having low to moderate or high levels of PA (IPAQ) or meeting the recommendation to accumulate 150 min of MVPA per week or 30 min of MVPA at least 3 times per week (accelerometry). Taken together these results suggest a similar proportion of OSI compared to ORI are following global recommendations to engage in PA, but their reasons for doing so may be more related to weight control. As a consequence, further promotion of PA recommendations to OSI may not be effective as they are either already meeting the recommendations or at least believe they are doing so.

In summary, it appears obesity resistant and obesity susceptible individuals engage in similar levels of PA and sedentary behaviour. Objective measures of PA, such as accelerometry may be more accurate at assessing PA than SRPAQ but the data is also collected over a shorter time frame, whereas data collected via SRPAQ may represent more usual PA, but be relatively insensitive. Therefore, the use of objective and subjective measures in a greater sample size of ORI and OSI may be better able to tease out small differences in overall PA which could have relevance in altering energy expenditure in the longer term.
3.4.5 Eating Behaviour

Eating behaviours can influence energy intake through the choices individuals make about when and where to eat, the types and amounts of food chosen and decisions about starting and stopping eating [76, 304]. In the B2BL study, the eating behaviour constructs of restrained eating, disinhibition and hunger were assessed using the TFEQ in ORI compared to OSI.

Previous research within the obesity resistance literature has reported lower restrained eating and disinhibition in thin versus reduced obese individuals [31, 32] and in obesity resistant versus obesity prone individuals [33, 34]. Similar results were observed in the present study with participants classified as resistant to obesity reporting significantly lower restrained eating and disinhibition than obesity susceptible participants. Interestingly, no significant differences were observed for hunger between ORI and OSI in the present study. Inconsistencies relating to this eating behaviour construct have been observed in the obesity resistance literature with some studies reporting no differences in hunger in thin versus reduced obese participants [31, 32] and others reporting lower hunger in ORI compared to obesity prone individuals [33, 34].

The eating behaviour constructs do not necessarily operate in isolation, but rather in combination. It has been suggested responsibility for the co-occurrence of restrained eating and disinhibition may lie more with disinhibition (and the potential resultant weight gain) causing restrained eating, rather than the other way around (Johnson, 2012). Higher disinhibition scores have been consistently associated with a higher BMI, higher energy intakes and less healthful food choices [305, 328, 331, 334, 336]. Therefore the lower disinhibition and restrained eating exhibited by ORI compared to OSI in the present study, despite similar reported hunger, may afford ORI some protection against overeating and the potential associated weight gain.

In summary, it appears eating behaviour is potentially different between obesity resistant and obesity susceptible individuals. Results from the TFEQ indicate that ORI may respond differently to hunger in that they are less likely to engage in
restrained eating and disinhibition behaviours. Physiological signals and behavioural cues both regulate appetite and energy intake, so whether this style of eating is an artifact of a differential response to hormone levels or a response to some psychological or learned behaviour remains to be determined in this group.

3.4.6 Strengths and Limitations
The B2BL study was unique for a number of reasons. It was the first study to investigate characteristics of obesity resistant individuals compared to obesity susceptible individuals in a New Zealand population. It is also one of a very small number of observational studies worldwide that have attempted to make comparisons between these two groups, the majority of which were designed to compare group responses under eucaloric, overfeeding and/or underfeeding conditions [26, 30-32, 34, 80, 82]. Additionally, a number of the assessments included within this study have not previously been part of studies conducted within the obesity resistance literature, such as:

i) Hormone concentrations and appetite responses to a standard meal following ad libitum diets.

ii) Full dietary intake analysis, including food group analysis and sensitivity analysis to identify low energy reporting.

iii) Accelerometry derived assessment of time spent in various different movement intensities, including sedentary behaviours and assessment of adherence to PA recommendations.

iv) Physical activity assessed subjectively using the IPAQ to determine PA in various domains and time spent sitting as a proxy for sedentary behaviour.

v) Assessment of eating frequency and time spent eating.

Previously, obesity resistant individuals have been variously defined as ‘lean’, ‘lean-resistant’, ‘thin’, ‘constitutionally thin’ and ‘obesity resistant’; while obesity susceptible individuals have been defined as ‘reduced obese’, ‘obesity prone’ and ‘obese-susceptible’. The most recently published studies (from 2012 onwards) have defined and selected obesity resistant and obesity prone participants using a combination of self-identification, BMI and personal/family weight history. In line
with these more recent definitions, the participants in the B2BL study self-identified and were classified as ORI or OSI based on their responses to a pre-tested screening tool developed by the research team.

The number of participants included in the different analyses in this study fluctuated depending on the available data for each variable. Although this number varied between 52 (adherence to MVPA recommendations) and 63 (body composition) participants, this sample size is larger or comparable to sample sizes reported in previously published studies within the obesity resistance literature.

Careful thought was given to the selection of the testing procedures used in this study to ensure that methodology considered to be the gold standard for each variable was employed. A range of measurement instruments were incorporated which included both objective and subjective tools. In addition, when necessary specialised practitioners and technicians were consulted to provide advice on best practice and in some instances assistance with data collection eg DXA scans, RMR assessment, accelerometer data analysis and statistical analysis.

Body composition was assessed using DXA scans, rather than less accurate, more indirect methods such as bioelectric impedance or skinfold thicknesses [482]. This ensured an accurate measurement of the various body tissue components (FFM, fat mass, and subsequently %BF) was obtained. This was especially important given that some variables were expressed relative to FFM (eg RMR) and many outcomes were adjusted for %BF.

The methods employed to assess RMR using indirect calorimetry and strict adherence to standardised pre-test protocols [130] ensured the reliability of the data collected. Each participant was provided with clear pre-test guidelines to follow. The Sensormedics 2900 metabolic cart (Sensormedics, California, USA) was calibrated each morning prior to the testing schedule beginning and was recalibrated if more than two participants were tested on a given day.
Using 4DDR to assess dietary intake has a number of advantages over other dietary assessment methods. Information is collected at the time of consumption, limiting recall bias, and information is obtained on actual intakes that can then be analysed to provide an assessment of specific nutrient intake per day. However, it must be acknowledged that one limitation of assessing dietary intake using diet records is the potential for the recording process to alter eating behaviour. Another acknowledged difficulty with using diet records to assess dietary intake is with the estimation of portion size. To improve the accuracy of portion size estimates, participants were provided with digital scales, food photographs and a set of measuring cups and spoons. The diet record collection period included 3 week days and 1 weekend day to take into account variation in dietary intake.

Physical activity (PA) was assessed using both objective (accelerometry) and subjective (IPAQ) methods in order to balance the positive aspects and limitations of these types of assessments. Including both forms enabled a number of different facets of PA to be measured including sedentary behaviour, time spent in various movement intensities, PA undertaken in different domains and adherence to PA recommendations.

Clear instructions, both verbal and written, were provided to participants regarding each different assessment. Simple, clear layouts were used in order to make all study documents as user-friendly as possible. In most instances, validated questionnaires and scales were used to increase the validity and reliability of the data collected.

Double entry of all study data, except the 4DDR, was undertaken to reduce error. The 4DDR were entered into the dietary analysis software once and then carefully rechecked to ensure all items had been entered and coded correctly. Appropriate variables were controlled for in the regression models. Any statistical assumptions that needed to be made were checked and satisfied in all cases. Where possible, variables were treated as continuous measures to avoid the arbitrariness of using a categorical variable, and to ensure maximum statistical power was achieved.
Despite these strengths, there are some limitations that should be considered when interpreting the results of the B2BL study. Most importantly, the cross-sectional design of the study does not allow for causal inferences to be drawn when looking at the association between variables at one time point. Consequently it is unknown, for example, whether OSI report a higher level of disinhibition than ORI because they are susceptible to obesity, or, if high levels of disinhibition leads to increased susceptibility to obesity. The power calculations used in the study were based on the number of participants required to detect a change in postprandial ghrelin concentrations. As such, despite having similar or even larger numbers of participants than previous research in the obesity resistance literature, a larger sample size may have been required to detect small changes between the two ORS categories for some variables, for example accelerometry counts and IPAQ responses.

A major limitation of the B2BL study relates to the screening tool used to classify ORI and OSI. While the tool has face validity, limitations in the screening tool may be responsible for the lack of perhaps expected differences in a number of the variables investigated. Firstly, the tool is unevenly weighted towards ORI with four statements related to ORI versus two statements related to OSI. Secondly, the obesity susceptible group is heterogeneous in nature, as it combines individuals who are currently overweight/obese with previously overweight/obese individuals who have undergone weight loss and healthy weight individuals who put considerable effort into avoiding weight gain. These sub-groups may differ regarding some of the characteristics studied. As a consequence, this variability in the OSI group may make it harder to detect significant differences between OSI and ORI.

As previously mentioned, ghrelin concentrations differ throughout the day in cyclic fashion in relation to meal taking and diurnal rhythms [91]. In the present study, ghrelin concentrations were assessed over a 4 h period in the morning. This represents a potential limitation in the interpretation of the ghrelin results as the analysis may simply have been unable to capture differences between the ORS categories.
The TFEQ, IPAQ and attitudes to exercise questionnaires were self-administered, therefore the questions were potentially open to different interpretations. Poor comprehension of the questionnaire is an acknowledged source of measurement error associated with SRPAQ [296, 297]. However, including self-administered questionnaires within the study design can have some advantages. Participants may feel more comfortable answering questions about their eating habits and physical activity in private, compared to an interview situation. Therefore, the preservation of anonymity may have encouraged participants to answer the questions more honestly.

The original wording of the questionnaires used in the B2BL study was not altered prior to administration in this study population. Inclusion of imperial measurement units such as 'lb' (pound) and 'calorie' and terms such as 'yard' without providing an alternative or an explanation of the term may have lead to potential misinterpretation due to the New Zealand participants in this study being unfamiliar with these words.

The socio-economic status (education level, occupation, income etc) of participants in the B2BL study is unknown. Participants were recruited from the general public in Dunedin, New Zealand and it is possible socio-economic status may have influenced the results of this study or their interpretation.
The Ice Tea (IceT) Study

4.1 Introduction

Following on from the Born to be Lean (B2BL) study, the Ice Tea (IceT) study was designed to investigate some further gaps identified in the obesity resistance literature. A potential consequence of living in an obesogenic environment is an excess energy intake due to the abundance of large portions of energy-dense, highly palatable, inexpensive and easily accessible food [9, 10]. How an individual responds to the intake of additional calories may be a feature of their resistance or susceptibility to obesity. It has been suggested that infants and young children are capable of regulating energy balance as they exhibit accurate compensatory behaviours [35, 36]. However, whether this ability extends into adulthood is unclear [37]. Resistance to the obesogenic environment may indicate that the compensatory capability present in childhood has been maintained in obesity resistant individuals (ORI). On the other hand a lack of precision in the ability to compensate for additional calories may explain why obesity susceptible individuals (OSI) struggle to maintain a healthy body weight (BW).

The obesogenic environment has the potential to interact with an individual's eating behaviour to influence resistance or susceptibility to obesity. Results from the small amount of work that has been conducted to date indicate there may be some differences in eating behaviour between ORI compared to OSI. For the majority of this work, the three-factor eating questionnaire (TFEQ) has been used to assess restrained eating, disinhibition and hunger in these groups. There are a number of other eating behaviour constructs, such as emotional eating, external eating and intuitive eating, that have yet to be examined in specifically defined ORI and OSI.

Hypersensitivity to fat may be one mechanism that allows some individuals to better regulate their BW. Recent investigations have reported an association between fat sensitivity and lower energy and fat intake, BMI and waist circumference (WC) [122-124]. Findings from the few studies using animal
models, suggests potential difference in sensitivity to fat in obesity resistant compared to obesity prone animals. No human studies have been conducted to investigate the link between obesity resistance and hypersensitivity to fat.

The primary aim of the IceT study intervention was:

- To compare the compensation capabilities of ORI and OSI in response to additional dietary energy intake.

The primary aims of the IceT nested cross-sectional studies were:

- To compare and contrast restrained eating, emotional eating, external eating and intuitive eating behaviours of ORI and OSI.

- To compare and contrast the sensitivity to oral fatty acid ingestion of ORI and OSI.
4.2 Methods

4.2.1 Overview
The ICE Tea intervention was a randomised, placebo-controlled, double-blind, parallel study comparing the capability of obesity resistant individuals (ORI) compared to obesity susceptible individuals (OSI) to compensate for additional calories. Twelve months after the B2BL study, obesity resistant and obesity susceptible participants were randomly assigned to receive either a 500 ml sugar-sweetened (SS) beverage (~1000 kJ) or a 500 ml artificially-sweetened (AS) beverage (~25 kJ) daily for 8 weeks. Beverages rather than food were selected, as the amount of energy delivered by the SS beverage could be easily controlled compared to a food option and the similarities in taste, appearance and packaging between the SS and AS beverages meant participants and researchers could be easily blinded to the intervention. Body composition, dietary intake, physical activity and blood lipids were assessed at baseline and at the end of the 8-week intervention.

Two cross-sectional analyses were also conducted using participants from the IceT Study cohort. In cross-sectional study 1, the eating behaviour of ORI compared to OSI was assessed using the Dutch Eating Behaviour Questionnaire (DEBQ) and the Intuitive Eating Scale (IES). Cross-sectional study 2 investigated the sensitivity to oral fatty acid ingestion in ORI compared to OSI.

4.2.2 Participant Characteristics

4.2.2.1 Recruitment
All IceT study advertising material was designed to include specific questions to target obesity resistant and obesity susceptible individuals (Appendix O). One hundred and seventy six members of the general public of Dunedin, New Zealand, responded to flyers, advertisements in local newspapers and emails sent to University of Otago staff and students.
4.2.2.2 Screening and Eligibility

To be eligible, participants were required to be healthy males aged between 20 and 55 y or females aged between 20 and 45 y, in order to limit recruitment to premenopausal women. Potential participants in the IceT study completed the same screening questionnaire as participants in the Born to be Lean (B2BL) Study to determine if they met the study criteria as either an ORI (remains lean with relative ease and can eat whatever they like) or an OSI (struggles to maintain their weight, despite perceived low energy intakes) (Table 3.1).

As with the B2BL study, participants were classified as ORI if they answered positively to any of the statements 1 – 4. Conversely, participants were classified as OSI if they answered positively to either of the statements 5 – 6. Participants were excluded if they did not answer positively to any of the screening tool statements, or if they were unable to be clearly classified as ORI or OSI. Exclusion criteria also included presence of chronic disease, menopause, smoking, pregnancy or intention to become pregnant in the next 3 months, lactation, history of an eating disorder, a thyroid disorder or other medical condition/s that could affect metabolic rate, intention to lose weight using informal or formal methods in the next 3 months, not currently consuming SS or AS beverages and phenylketonuria as the AS study beverage contained phenylalanine.

Of the 176 respondents assessed for eligibility, 58 were excluded from entering the study due to not meeting the exclusion criteria (n=20), declining to participate (n=30), unexpected illness (n=3), and undergoing the screening process after the quota for ORI males had been exceeded (n=5) (Figure 4.1). A total of 118 participants (63 ORI and 55 OSI) were successfully screened and recruited to take part in the study.

4.2.3 Ethical Approval, Informed Consent and Clinical Trial Registration

The primary outcome of interest in this study was energy balance and change in BW. However we did not want to emphasise BW to the participants as this can affect the way in which people behave. We therefore emphasised to participants
**Figure 4.1.** Flow diagram of obesity resistant individuals (ORI) and obesity susceptible individuals (OSI) assigned to consume a sugar-sweetened (SS) or artifically-sweetened (AS) beverage in the Ice Tea (IceT) study

176 Assessed for eligibility

58 Excluded
- 13 unable to be clearly classified as ORI or OSI
- 1 recently quit smoking (3 weeks)
- 1 diagnosed medical condition that could affect metabolic rate
- 3 planned on losing weight in the next 3 months
- 2 did not normally consume SS or AS beverages
- 30 declined to participate
- 3 unexpected illness
- 5 ORI males screened after the ORI male quota had been reached

118 Randomised

57 Assigned to SS Beverage
- 30 ORI
  - 30 Analysed
  
- 27 OSI
  - 27 Analysed

61 Assigned to AS Beverage
- 33 ORI
  - 33 Analysed
  - 1 Excluded
    - 1 began a weight loss programme

- 28 OSI
  - 26 Analysed
  - 1 withdrew
    - 1 for personal reasons
that the outcome we were interested in was the impact of green tea extract intake on blood cholesterol levels. Thus some deception was involved, but this was considered critical to the study design. The study protocol was approved by the Human Ethics Committee of the University of Otago, New Zealand (Appendix P). All participants provided written informed consent (Appendix Q, R). The IceT study was registered with the Australia New Zealand Clinical Trials Registry (ANZCTR) (Trial ID: ACTRN12610000106033).

4.2.4 Randomisation and Retention
Figure 4.1 provides detail on the flow of participants through the IceT study from recruitment, randomisation to study groups, and retention during the 8-week intervention. Thirty ORI and 27 OSI were randomly assigned to consume a SS beverage (ORI/SS and OSI/SS, respectively), while 33 ORI and 28 OSI were randomly assigned to consume an AS beverage (ORI/AS and OSI/AS, respectively), once daily for 8 weeks. Allocation to study beverage group was conducted by an off-site statistician, who had no involvement in the enrolment process. Participants were randomly assigned to the SS or AS beverage using computer-generated allocation using random length blocks stratified by obesity resistance/susceptibility (ORS) category. One participant withdrew from the OSI/AS group during the intervention due to personal reasons. Another participant from the OSI/AS disclosed they had begun an exercise programme during the intervention period for the purposes of losing weight. This violated the exclusion criteria for the IceT study so this participant was removed from all data analyses. All ORI/SS, OSI/SS, and ORI/AS completed the study as did 26 of the 28 OSI/AS participants.

4.2.5 Study Beverages
4.2.5.1 Selection
Two non-carbonated beverages, that were palatable enough for participants to consume every day for 8 weeks, were required for the IceT study. One beverage needed to act as a vehicle to deliver ~1000 kJ of energy in a single serve and the second needed to be a very low calorie control with the same serving size and
similar taste, appearance and packaging to the first. A small pilot study involving six participants was undertaken to assess the taste, appearance, palatability and acceptance for use of six SS beverages and their matched AS counterparts. The beverages that were evaluated are described and listed from highest to lowest rating in Table 4.1.

**Table 4.1.** Sugar-sweetened (SS) and matched artificially-sweetened (AS) test beverages assessed for potential use in the IceT study listed from highest to lowest rating

<table>
<thead>
<tr>
<th>Sugar-sweetened (SS) Test Beverage</th>
<th>Artificially-sweetened (AS) Test Beverage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lipton® Green Ice Tea - Citrus</td>
<td>Lipton® Light Green Ice Tea - Lemon</td>
</tr>
<tr>
<td>*Baker Halls® Fruit Syrup - Lemon Barley</td>
<td>Baker Halls® Low Calorie - Lemon Barley</td>
</tr>
<tr>
<td>*Baker Halls® Fruit Syrup - Blackcurrant</td>
<td>Baker Halls® Low Calorie - Blackcurrant</td>
</tr>
<tr>
<td>*Baker Halls® Fruit Syrup - Orange Barley</td>
<td>Baker Halls® Low Calorie - Orange Barley</td>
</tr>
<tr>
<td>Ocean Spray® - Cranberry</td>
<td>Ocean Spray® Light - Cranberry</td>
</tr>
<tr>
<td>*Baker Halls® Fruit Syrup - Lime</td>
<td>Baker Halls® Low Calorie - Lime</td>
</tr>
</tbody>
</table>

* indicates the beverage was diluted to provide the equivalent of 1000 kJ per 500 ml serve

The four Baker Halls® Fruit Syrup SS beverages were diluted to a concentration equivalent to providing 1000 kJ per 500 ml serving. The remaining Ocean Spray® and Lipton® SS beverages did not require dilution. The Lipton® Green Ice Tea test beverages achieved the highest ratings and were subsequently selected as the study beverages for the IceT study (Figure 4.2).
Other than the product labels, which were removed, the drinks were indistinguishable by smell and appearance and came prepackaged in a 500 ml bottle. Details of the ingredients and nutrient content of both beverages can be found in Table 4.2.

4.2.5.2 Modification of the Sugar-Sweetened (SS) Beverage
The AS beverage was sweetened with acesulphame potassium (artificial sweetener 950) and aspartame (artificial sweetener 951) so it was low in calories (25 kJ per 500 ml serve). It also contained similar amounts of sodium, flavonoid antioxidants and caffeine as the SS beverage so could be directly used in the IceT study in the state it was manufactured. In its commercially available form, the SS beverage only contained 595 kJ per 500 ml serve. In order to increase the energy content to

Figure 4.2. The Ice Tea (IceT) study beverages
1000 kJ per serve, 20 ml of the SS beverage was removed from each 500 ml serve and 26.3 g of powdered maltodextrin (Glucidex® IT 12, Roquette Frères, Lestrem, France) was added (Table 4.2). Glucidex® IT 12 is a dissolvable, easily digested, tasteless and odourless food grade polysaccharide.

**Table 4.2.** Nutrient content and ingredient list of the sugar-sweetened (SS) and artificially-sweetened (AS) beverages

<table>
<thead>
<tr>
<th></th>
<th>Lipton® Light Green Ice Tea Lemon Flavour (AS Beverage)</th>
<th>Lipton® Green Ice Tea Citrus Flavour</th>
<th>Lipton® Green Ice Tea Citrus Flavour + maltodextrin (SS Beverage)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy (kJ)</td>
<td>25</td>
<td>595</td>
<td>1000</td>
</tr>
<tr>
<td>Protein (g)</td>
<td>&lt;0.5</td>
<td>&lt;0.5</td>
<td>&lt;0.5</td>
</tr>
<tr>
<td>Fat, Total (g)</td>
<td>&lt;0.5</td>
<td>&lt;0.5</td>
<td>&lt;0.5</td>
</tr>
<tr>
<td>Fat, Saturated (g)</td>
<td>&lt;0.5</td>
<td>&lt;0.5</td>
<td>&lt;0.5</td>
</tr>
<tr>
<td>CHO, Total (g)</td>
<td>&lt;0.5</td>
<td>34.5</td>
<td>58.3</td>
</tr>
<tr>
<td>Sugar (g)</td>
<td>&lt;0.5</td>
<td>34.5</td>
<td>33.9</td>
</tr>
<tr>
<td>Sodium (mg)</td>
<td>60</td>
<td>&lt;25</td>
<td>&lt;24.3</td>
</tr>
<tr>
<td>Flavonoid Antioxidants (mg)</td>
<td>130</td>
<td>130</td>
<td>125</td>
</tr>
<tr>
<td>Caffeine (mg)</td>
<td>∼80</td>
<td>∼80</td>
<td>∼77</td>
</tr>
<tr>
<td>Ingredients</td>
<td>water, green tea extract (10.8%), food acids (330, 331), lemon juice, flavour, antioxidant (300), artificial sweeteners (950, 951)</td>
<td>water, green tea extract (10.8%), sugar, food acids (330, 331), lemon juice, flavour, antioxidant (300)</td>
<td>water, green tea extract (10.8%), sugar, maltodextrin, food acids (330, 331), lemon juice, flavour, antioxidant (300)</td>
</tr>
</tbody>
</table>

Values for nutrients and caffeine are expressed as grams or milligrams per 500 ml serve

AS = artificially-sweetened, CHO = carbohydrate, SS = sugar-sweetened

**4.2.5.3 Blinding of Study Beverages**

A number of procedures were followed to ensure that both the researchers and participants remained blinded as to which beverage was which. As the bottles of SS beverage needed to be opened to allow the addition of the maltodextrin, all study beverage bottles (both SS and AS) were opened and the caps re-screwed.
prior to distribution to the participants. The candidate was responsible for modifying the SS beverage. In a separate room, a research assistant removed the product label from all the study beverage bottles and replaced it with a plain label containing the name of the study and ‘A’ or ‘B’. This research assistant, who did not have any contact with the study participants and was not involved with any of the data analysis, was the only member of the study team who was aware which study beverage the ‘A’ and ‘B’ were coded for. This information was disclosed to the rest of the study team once all data had been analysed.

4.2.6 Study Design
A flow chart illustrating the study methods is outlined in Figure 4.3.

4.2.6.1 Anthropometry and Body Composition
Each participant attended an initial 30 min clinic visit at the Department of Human Nutrition, University of Otago following a 12-hour overnight fast. Measurements of BW, height and waist circumference (WC) were obtained following the same procedures used in the B2BL study (see section 3.2.4.1 for detail). Body mass index (BMI) was calculated by dividing BW in kilograms by the height in metres squared. All anthropometric measurements were repeated at the end of the 8-week intervention.

Body composition (lean body mass (LBM), fat mass and percentage body fat (%BF)) was measured using dual-energy x-ray absorptiometry (DXA; Lunar Prodigy, GE Medical Systems, Madison WI, USA) running enCore software, version 12.3 at the Dunedin Public Hospital Dual X-Ray Absorptiometry Scanning Unit during the one to two weeks following the initial clinic visit (baseline) and during week 8 of the intervention.

4.2.6.2 Blood Cholesterol Sampling
During the initial clinic visit and at the end of the 8 week intervention, a 10 ml venous blood sample was obtained by a registered nurse and collected into Vacutainers® (Becton Dickinson Diagnostics) containing disodium EDTA for the
Figure 4.3. Flow diagram of Ice Tea (IceT) study methods

Baseline Measures:
- (week -2)
  - Anthropometry 0
  - Blood sample 0

Baseline

Intervention

End of Intervention Measures:
- Anthropometry 1
- Blood sample 1
- Questionnaires
- Beverage use, DEBQ, IES
- Sensitivity to oral fatty acid ingestion

Baseline Measures:
- (week -2 to 0)
  - Accelerometer 0 (7 d)
  - Diet record 0 (4 d)
  - DXA 0

Beverage Collection/Delivery

Timepoints:
Week 0, 2, 4, 6

End of Intervention Measures:
- (during week 8)
  - Accelerometer 1 (7 d)
  - Diet record 1 (4 d)
  - DXA 1
analysis of plasma blood lipids and lipoprotein concentrations. Vacutainers were inverted and temporarily stored in an insulated container with chilled ice-packs. Within 2 hours of being drawn, all blood specimens were centrifuged at 3000 G for 15 min at 4°C to separate plasma and red blood cells. Plasma aliquots were stored at -80°C until analysis.

Plasma total cholesterol (TC), high density lipoprotein cholesterol (HDL-C), and triacylglyceride (TAG) concentrations were measured in both blood samples for all participants on a Cobas Mira Plus Analyser using enzymatic methods (Roche Diagnostics, Mannheim, Germany). Plasma low density lipoprotein cholesterol (LDL-C) was calculated using the Friedewald formula [483].

### 4.2.6.3 Dietary Intake

In the one to two weeks after the initial clinic visit (during the baseline period), and in the final week of the intervention, participants were asked to complete a four-day weighed food record (4DDR) following the same procedures used in the B2BL study (see section 3.2.8.1 for detail). Participants were instructed on how to complete a diet record (Appendix S) and were issued with the first recording booklet during breakfast time at the initial clinic visit. Participants were issued with the second recording booklet in week 7 of the intervention and given a recap of the instructions for completing the diet record.

The analysis of the 4DDRs (total of 928 days) was unable to be completed in time for submission of this thesis. Dietary intake results for the IceT study are therefore not reported in this thesis. The 4DDR analysis will be completed and the results incorporated into a future publication.

### 4.2.6.4 Physical Activity (PA)

As outlined previously, the primary outcome measure of interest in the IceT study was energy balance and change in BW. Therefore, it was important to include a measure of habitual PA. The Actical accelerometers used in the B2BL study were loaned from another research group and were unavailable for use in the IceT study.
An alternative accelerometer was sought that could provide useful PA data, was easy for participants to wear and that fit within the constraints of the study budget. The NL-1000 (New-Lifestyles Inc., USA) is a small, piezoelectric pedometer that measures vertical acceleration to count steps and accumulates total activity time spent at or above moderate intensity (i.e., MVPA) using a medical-grade accelerometer. For the calculation of MVPA (moderate-intensity and vigorous-intensity physical activity) time, the NL-1000 activity minute timer was set at an activity intensity range of 4 – 9. This corresponds to an equivalent range of 3.6 to >8.3 MET. The NL-1000 samples activity intensity every 4 s [484]. Each 4 s period that is determined to be at or above the MVPA lower threshold of 4 is added to the total activity minutes [484]. The accuracy and inter-instrument reliability of the NL1000 for recording steps taken and minutes of MVPA has been confirmed previously in adult populations [485, 486].

Participants were issued with an accelerometer at the end of the initial clinic visit and again in week 7 of the intervention and asked to wear the accelerometer for a period of seven consecutive days. Participants were given detailed instructions on how to wear the accelerometer clipped to their clothing at waist level. (Appendix T). Participants were asked to attach the accelerometer as soon as they got out of bed in the morning, to wear it for the whole day, and to remove it last thing before getting into bed at night. As the NL-1000 is not waterproof, participants were asked to remove the device when showering, bathing, swimming or engaging in other water-based activities and also during activities that may have been harmful to the device (e.g., contact or combat sports). The accelerometer was sealed so that participants could not open the device and thus were blinded to any feedback on their PA.

After the accelerometer was returned, PA data were retrieved from the 7 d memory of each device. Number of steps and distance and time spent in MVPA was recorded. If the total number of steps for any given day was <2000 this day was not included in analyses as a valid day. It was determined during experimentation with the NL-1000 activity monitors that it is extremely difficult for an individual to accumulate such a small number of steps during a day unless
some error in the positioning of the monitor has occurred or the monitor has not been worn for the whole day. The average number of steps, and time spent in MVPA were calculated from valid days at baseline and during the last week of the 8 week intervention.

4.2.6.5 **Beverage Allocation, Distribution and Compliance**

Participants were randomly assigned to receive either the SS beverage or the AS beverage. Participants were instructed to consume one 500ml bottle per day between the hours of 8am and 8pm for 8 weeks. This twelve hour time period was chosen to allow participants flexibility in choosing when to consume the beverage and to allow a sufficient window for potential compensation to occur. Participants were further instructed that the manner in which the beverages were consumed was entirely at their discretion i.e. they may choose to consume the daily serving in its entirety in one short sitting, or spread the consumption over a longer time period or even sipped throughout the day. The method of consumption could also vary between days throughout the 8-week study period. Beverages were either collected from the Department of Human Nutrition or delivered to participant’s home or workplace fortnightly.

4.2.6.5.1 **Study Beverage Acceptability Assessment**

In an effort to enhance compliance during the 8-week intervention, the acceptability of the study beverages was assessed in each participant before randomisation. During the initial clinic visit, participants were presented with a 20 ml sample of both the SS and AS beverages in small plastic test cups. After sampling each beverage, participants were verbally asked if they thought they would be able to consume 500 ml of either beverage each day for the 8-week duration of the study. All participants indicated both beverages were acceptable.

4.2.6.5.2 **Compliance to Study Intervention**

Participants were asked to consume a total of 56, 500 ml serves of study beverage during the course of the intervention. In order to assess compliance, participants were issued with a ‘tick sheet’ (Appendix U). Participants were asked to indicate
on the ‘tick sheet’ if they did (by a tick) or did not (by a cross) consume the beverage on any particular day. If for some reason they did not consume the whole beverage then the amount they did consume could also be recorded. The ‘tick sheet’ was returned on the last day of the 8-week intervention.

4.2.6.6 **Beverage Use Questionnaire**

In order to understand how participants incorporated the study beverages into their daily lives, participants completed a beverage use questionnaire during the clinic visit on the last day of the intervention (Appendix V). Participants were presented with a number of statements (e.g. ‘I usually drank the ice tea provided instead of a drink I would normally have consumed’, ‘I usually drank the ice tea as part of a main meal’ and ‘I usually drank the ice tea sipped throughout the day’) and asked to indicate all statements that most accurately described how they consumed the study beverages. The proportion of participants indicating a positive response to each statement was calculated.

4.2.7 **Cross-Sectional Study 1: Eating Behaviour**

Two validated eating behaviour questionnaires, measuring different eating behaviour constructs to those assessed in the B2BL study, were also administered to participants during the clinic visit on the last day of the IceT Study intervention.

The Dutch Eating Behaviour Questionnaire (DEBQ) [309] is a 33 item self-administered questionnaire that identifies three different constructs of eating behaviour: restrained eating (e.g. ‘Do you watch exactly what you eat?’), emotional eating (e.g. ‘Do you have a desire to eat when you are feeling lonely?’) and external eating (e.g. ‘If food smells and looks good, do you eat more than usual?’) (Appendix W). A five point Likert scale (never=1, seldom=2, sometimes=3, often=4, very often=5) is used by respondents to indicate their acceptance of each statement. Summed totals of each section of questions relating to the three eating behaviours were calculated. Details of the scoring of the DEBQ can be found in Appendix W.
The original Intuitive Eating Scale (IES) [310] was used as this study was conducted before publication of the revised IES-2 [311]. The IES is a 21 item self-administered questionnaire, which consists of 3 subscales: unconditional permission to eat (eg ‘If I am craving a certain food, I allow myself to have it’), eating for physical rather than emotional reasons (eg ‘I find myself eating when I am bored, even when I am not hungry’), and reliance on internal hunger/satiety cues (eg ‘I trust my body to tell me when to eat’) (Appendix X). A five point Likert scale (strongly disagree, disagree, neutral, agree and strongly agree) is used by respondents to indicate their agreement with each statement. A total score and totals for each of the three subscales of intuitive eating were calculated using the IES scoring template (Appendix X).

4.2.8 Cross-Sectional Study 2: Sensitivity to Oral Fatty Acid Ingestion

4.2.8.1 Overview and Ethical Approval
Participants in the IceT study were invited to take part in an assessment of oral fatty acid sensitivity in order to investigate potential differences in oral hypersensitivity to fat in ORI compared to OSI (Appendix Y). This research was approved by the Human Ethics Committee of the University of Otago (Appendix Z). All participants provided written informed consent (Appendix AA, AB). Eighty-six participants (50 ORI, 36 OSI) attended a tasting session at the sensory laboratory in the Department of Food Science, University of Otago. Prior to the tasting session participants were instructed to avoid drinking strong tea or coffee for at least 1 hour and to avoid wearing strong perfume. Participants were also asked to avoid consuming a large meal and to come to the tasting session no more than 70-80% full. Nose clips were worn during the tasting session.

4.2.8.2 Oral Fatty Acid Tasting Session
Oral sensitivity to oleic acid (1.4 mM) was determined by using triplicate triangle tests based on the methods by Stewart et al [123]. Participants were presented with three milk samples, consisting of one sample with oleic acid (1.4 mM, Sigma Aldrich, St Louis, MO, USA) and two control samples without oleic acid.
Hypersensitive individuals were defined as those who correctly identified the oleic acid sample in all three tests (a one in 27 chance, approximately 4%, by random guessing). All other individuals were defined as hyposensitive (getting two correct by chance would occur approximately 22% of the time, one correct approximately 44% of the time, and none correct approximately 30% of the time).

4.2.8.3 Fat Ranking Test
Participants performed a fat ranking test which examined their ability to differentiate the fat content of custards containing 0%, 2%, 6%, and 10% canola oil (Sunfield, Tasti Products Ltd, Auckland, New Zealand). Participants were presented with the custard in random order and asked to rank the custard samples from the highest to the lowest fat level. Participants were given a score based on their ability to rank the samples using a system based on a previous study by Stewart et al [123]. A score of five indicated that the observed rank was the same as the true rank e.g. the observed rank was 0%, 2%, 6% and 10%. On the other hand, a score of zero meant that the observed rank was far from the true rank e.g. the fat-free custard and custard with the highest fat content (10%) were ranked next to each other.

4.2.9 Statistical Analysis
Statistical analysis was performed using STATA Version 12.1 (STATA Inc., College Station, TX, USA). All statistical tests were two-sided and P<0.05 was considered statistically significant.

4.2.9.1 Sample Size and Participant Characteristics
The primary outcome measure of the IceT intervention was BW. Thirty participants (15 female and 15 female) per group (ORI/SS, ORI/AS, OSI/SS and OSI/AS) were required to detect a difference of 2kg in BW between groups with a power of 90% and alpha 0.05. This power calculation was based on a standard deviation of 12 kg for BW and a correlation between baseline and follow-up values of 0.98 (data from a previous weight maintenance study [487]). Therefore a total
of 120 participants were needed for recruitment. Participant characteristics are presented as arithmetic means and SD.

4.2.9.2 Impact of Sugar-Sweetened (SS) Versus Artificially-Sweetened (AS) Beverage Consumption on Body Composition Analysis

The effects of the two interventions on all outcomes were examined by using regression models controlling for baseline values, sex and %BF. Effect sizes and 95% CI for differences in changes between groups were examined. Interactions between intervention and ORS category were used to examine if the ORI and OSI responded differently to the intervention. All analyses were performed using a modified intention-to-treat principle in which participants with available data were analysed as per their allotted treatment.

4.2.9.3 Beverage Use Questionnaire Analysis

Frequencies and percentages of participants responding positively to the statements regarding beverage use were calculated. Depending on the number of respondents to the categorical variables, differences in the percentage of respondents between ORS category intervention groups were examined using Chi-square test when there were no more than 20% of expected cell frequencies below 5, and Fisher’s Exact test otherwise.

4.2.9.4 Cross-Sectional Study 1: Eating Behaviour Questionnaire Analysis

The relationship between ORS category and subscale scores from the DEBQ and the IES and total intuitive eating score were assessed using regression modeling controlling for sex and %BF. Eating behaviour questionnaire data are presented as arithmetic means and 95%CI. The estimated difference between ORI and OSI is also presented as means and 95%CI. An interaction between sex and ORS category was considered for all eating behaviour variables.
4.2.9.5 **Cross-Sectional Study 2: Sensitivity to Oral Fatty Acid Ingestion**

Participant characteristics are presented as arithmetic means and standard deviations (SD). Linear regression models adjusted for sex were used to compare baseline variables between ORI and OSI.

Logistic regression models for oral fatty acid sensitivity were developed with the goal of limiting the number of predictors to one for each 10 non-events and 10 events using the guidelines from Peduzzi, et al [450]. The modelling process used Greenland’s [488] approach to select potential confounders in the association between being an ORI/OSI and sensitivity with variables added in a forward selection process where they changed the odds ratio (OR) by at least 10% from the previous model and with the variable changing the OR by the greatest percentage being added where multiple candidate variables were identified at a given stage. The full set of potential confounders was sex, age (in y), BW (in kg), height (in m), BMI, WC (in cm), and %BF. As several variables involved body composition (BW, BMI, WC, and %BF) and these were expected to be correlated, once one body composition variable was added, the others were no longer considered. The Hosmer-Lemeshow test and a model specification test were used to assess goodness of fit. For all regression models, the addition of a quadratic term for each continuous predictor was investigated to detect, and if significant model, non-linear associations. Such quadratic terms were retained if statistically significant.

In a similar way, Poisson regression was used to compare fat ranking scores between ORIs and OSIs with negative binomial regression used where there was evidence of over-dispersion from a likelihood ratio test. The number of variables was limited to one for each ten observations for these models. For all regression models, the addition of a quadratic term for each continuous predictor was investigated to detect, and if significant model, non-linear associations. Such quadratic terms were retained if statistically significant.
4.3 Results

4.3.1 Participant Characteristics

Baseline characteristics of the IceT study participants (n=116) are presented in Table 4.3. The four groups (ORI/SS, OSI/SS, ORI/AS and OSI/AS) were well balanced with respect to these baseline characteristics within each ORS category.

Table 4.3. Baseline characteristics of obesity resistant individuals (ORI) and obesity susceptible individuals (OSI) assigned to the sugar-sweetened (SS) beverage and artificially-sweetened (AS) beverage groups.

<table>
<thead>
<tr>
<th></th>
<th>SS Beverage</th>
<th></th>
<th>AS Beverage</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>ORI</td>
<td>OSI</td>
<td>ORI</td>
<td>OSI</td>
</tr>
<tr>
<td>N</td>
<td>30</td>
<td>27</td>
<td>33</td>
<td>26</td>
</tr>
<tr>
<td>Age (y)</td>
<td>26.0 (6.9)</td>
<td>29.1 (9.6)</td>
<td>29.1 (8.1)</td>
<td>35.3 (11.4)</td>
</tr>
<tr>
<td>Female(a, (n))</td>
<td>14 (47)</td>
<td>15 (56)</td>
<td>16 (48)</td>
<td>13 (50)</td>
</tr>
<tr>
<td>BW (kg)</td>
<td>67.6 (10.1)</td>
<td>77.2 (18.0)</td>
<td>64.6 (11.6)</td>
<td>75.6 (15.3)</td>
</tr>
<tr>
<td>Height (m)</td>
<td>1.76 (0.09)</td>
<td>1.69 (0.10)</td>
<td>1.73 (0.08)</td>
<td>1.69 (0.08)</td>
</tr>
<tr>
<td>BMI (kg.m(^2))</td>
<td>21.8 (2.2)</td>
<td>26.7 (4.9)</td>
<td>21.5 (2.6)</td>
<td>26.3 (3.9)</td>
</tr>
<tr>
<td>WC (cm)</td>
<td>73.8 (6.2)</td>
<td>83.2 (13.5)</td>
<td>72.9 (8.6)</td>
<td>84.3 (12.3)</td>
</tr>
<tr>
<td>LBM (kg)</td>
<td>51.5 (11.1)</td>
<td>50.9 (12.6)</td>
<td>48.8 (11.2)</td>
<td>50.5 (11.7)</td>
</tr>
<tr>
<td>Fat Mass (kg)</td>
<td>13.9 (5.1)</td>
<td>23.6 (12.8)</td>
<td>15.5 (11.0)</td>
<td>22.5 (7.9)</td>
</tr>
<tr>
<td>%BF</td>
<td>20.8 (7.7)</td>
<td>29.7 (11.5)</td>
<td>21.1 (9.0)</td>
<td>29.5 (8.3)</td>
</tr>
<tr>
<td>Steps (n.d(^{-1}))</td>
<td>9528 (2362)</td>
<td>10152 (4194)</td>
<td>9312 (2601)</td>
<td>10111 (2366)</td>
</tr>
<tr>
<td>Distance (km.d(^{-1}))</td>
<td>4.7 (1.1)</td>
<td>5.0 (2.0)</td>
<td>4.6 (1.2)</td>
<td>5.0 (1.1)</td>
</tr>
<tr>
<td>MVPA (min.d(^{-1}))</td>
<td>41.6 (14.6)</td>
<td>42.2 (20.9)</td>
<td>41.3 (16.0)</td>
<td>41.8 (16.9)</td>
</tr>
</tbody>
</table>

All values are means (SD) except \(\text{a}\) indicates n (%)


4.3.2 Compliance

The degree of compliance, assessed by tick sheets, was reportedly 93.5% for ORI/SS, 95.8%, for OSI/SS, 94.3% for ORI/AS, and 93.0% for OSI/AS, with no significant differences in compliance between treatments (P=0.751).
4.3.3 The IceT Study Intervention:
Impact of a Sugar-Sweetened (SS) Beverage versus an Artificially-Sweetened (AS) Beverage on Body Composition Amongst Obesity Resistant Individuals (ORI) and Obesity Susceptible Individuals (OSI)
Table 4.4 and Figure 4.4 show the change in BW and various body composition variables amongst ORI and OSI consuming either the SS or AS beverage. There was a statistically significant increase in BW among those consuming the SS beverage compared to the AS beverage (P=0.016). However, there was no evidence of an interaction between ORS category and the intervention for BW (P=0.191), suggesting ORI and OSI did not respond differently to the intervention.

Body mass index (BMI), WC and %BF followed a similar pattern to BW in response to the intervention. There was a statistically significant increase in these variables following the consumption of the SS beverage compared to the AS beverage (P≤0.028). By contrast, the intervention had no statistically significant effect on LBM for either group. In addition, there was no evidence of an interaction between ORS category and the intervention for any of these body composition variables.

There were no statistically significant differences in the activity levels between those consuming the SS beverage and those consuming the AS beverage from baseline to 8 weeks (all P≥0.701). In addition, there was no evidence of an interaction between ORS category and the intervention for physical activity (P≥0.350).

4.3.4 Blood Lipids
Results of the blood lipid analysis are presented in Table 4.5. At the end of the 8 week intervention, no significant differences were observed in concentrations of TC, LDL-C, HDL-C, TAG or the ratio of TC to HDL-C (TC:HDL) in those who consumed the SS beverage versus those who consumed the AS beverage. Further, there was no evidence of an interaction between ORS category and the intervention for any of the blood lipid variables.
Table 4.4. Change in body composition variable among obesity resistant individuals (ORI) and obesity susceptible individuals (OSI) following 8 weeks daily consumption of 500 ml of a sugar-sweetened (SS) beverage (1000 kJ) compared to an artificially-sweetened (AS) beverage (25 kJ)

<table>
<thead>
<tr>
<th>Variable</th>
<th>SS Beverage</th>
<th></th>
<th></th>
<th>AS Beverage</th>
<th></th>
<th></th>
<th></th>
<th></th>
<th>P-value</th>
<th></th>
<th></th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>ORI</td>
<td>OSI</td>
<td></td>
<td>ORI</td>
<td>OSI</td>
<td>Interaction</td>
<td>Intervention</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>n</td>
<td>0.9 (0.4, 1.3)</td>
<td>0.8 (0.1, 1.5)</td>
<td></td>
<td>-0.2 (-0.7, 0.3)</td>
<td>0.5 (-0.1, 1.1)</td>
<td>0.191</td>
<td><strong>0.016</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BW (kg)</td>
<td>0.3 (0.1, 0.4)</td>
<td>0.3 (0.0, 0.5)</td>
<td></td>
<td>-0.1 (-0.2, 0.1)</td>
<td>0.2 (0, 0.4)</td>
<td>0.253</td>
<td><strong>0.018</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BMI (kg.m²)</td>
<td>1.0 (0.4, 1.5)</td>
<td>1.0 (0.1, 1.9)</td>
<td></td>
<td>0.3 (-0.3, 0.9)</td>
<td>0.1 (-0.8, 1.0)</td>
<td>0.771</td>
<td><strong>0.028</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>WC (cm)</td>
<td>0.4 (-0.2, 1.0)</td>
<td>0.9 (0.3, 1.6)</td>
<td></td>
<td>-0.4 (-1.1, 0.3)</td>
<td>0.1 (-0.5, 0.6)</td>
<td>0.891</td>
<td><strong>0.008</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>%BF</td>
<td>0 (-0.4, 0.5)</td>
<td>0.1 (-0.4, 0.6)</td>
<td></td>
<td>0 (-0.4, 0.4)</td>
<td>0.3 (-0.3, 0.8)</td>
<td>0.605</td>
<td>0.932</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

All values are means (95% CI)

Figure 4.4. Change in body composition variables (a: body mass, b: body mass index, c: waist circumference, d: percentage body fat, e: lean body mass) of obesity resistant individuals consuming either a sugar-sweetened (ORI/SS) or artificially-sweetened (ORI/AS) beverage and obesity susceptible individuals consuming either a sugar-sweetened (OSI/SS) or artificially-sweetened (OSI/AS) beverage daily for 8 weeks. Values are means ± SE. * indicates an intervention effect between ORI/AS and ORI/SS (P<0.012). No interaction effects between ORS category and intervention (all P>0.191).
Table 4.5. Blood lipid variables among obesity resistant individuals (ORI) and obesity susceptible individuals (OSI) as baseline and following 8 weeks daily consumption of 500 ml of a sugar-sweetened (SS) beverage (1000 kJ) compared to an artificially-sweetened (AS) beverage (25 kJ)

<table>
<thead>
<tr>
<th>Blood Lipid Variable</th>
<th>ORI/AS Baseline</th>
<th>ORI/AS Post-Intervention</th>
<th>ORI/SS Baseline</th>
<th>ORI/SS Post-Intervention</th>
<th>OSI/AS Baseline</th>
<th>OSI/AS Post-Intervention</th>
<th>OSI/SS Baseline</th>
<th>OSI/SS Post-Intervention</th>
<th>P-value for Interaction</th>
<th>P-value for Intervention</th>
</tr>
</thead>
<tbody>
<tr>
<td>TC (mmol.L⁻¹)</td>
<td>4.21 (3.93, 4.49)</td>
<td>4.37 (4.12, 4.62)</td>
<td>4.29 (4.05, 4.54)</td>
<td>4.25 (3.96, 4.54)</td>
<td>4.92 (4.50, 5.35)</td>
<td>4.94 (4.52, 5.36)</td>
<td>5.14 (4.75, 5.53)</td>
<td>5.03 (4.65, 5.40)</td>
<td>0.657</td>
<td>0.253</td>
</tr>
<tr>
<td>LDL-C (mmol.L⁻¹)</td>
<td>2.50 (2.27, 2.73)</td>
<td>2.61 (2.37, 2.84)</td>
<td>2.48 (2.28, 2.68)</td>
<td>2.36 (2.10, 2.63)</td>
<td>3.09 (2.71, 3.48)</td>
<td>3.15 (2.76, 3.54)</td>
<td>3.32 (2.95, 3.69)</td>
<td>3.12 (2.76, 3.48)</td>
<td>0.889</td>
<td>0.073</td>
</tr>
<tr>
<td>HDL-C (mmol.L⁻¹)</td>
<td>1.25 (1.13, 1.36)</td>
<td>1.26 (1.20, 1.41)</td>
<td>1.38 (1.23, 1.52)</td>
<td>1.40 (1.26, 1.54)</td>
<td>1.26 (1.10, 1.41)</td>
<td>1.23 (1.08, 1.38)</td>
<td>1.34 (1.20, 1.48)</td>
<td>1.32 (1.20, 1.48)</td>
<td>0.925</td>
<td>0.543</td>
</tr>
<tr>
<td>TAG (mmol.L⁻¹)</td>
<td>1.00 (0.85, 1.14)</td>
<td>1.00 (0.81, 1.20)</td>
<td>0.96 (0.83, 1.09)</td>
<td>1.06 (0.79, 1.33)</td>
<td>1.25 (1.00, 1.51)</td>
<td>1.21 (1.00, 1.42)</td>
<td>1.06 (0.84, 1.27)</td>
<td>1.27 (0.99, 1.55)</td>
<td>0.374</td>
<td>0.066</td>
</tr>
<tr>
<td>TC:HDL</td>
<td>3.5 (3.2, 3.9)</td>
<td>3.6 (3.2, 4.0)</td>
<td>3.3 (3.0, 3.6)</td>
<td>3.2 (2.9, 3.6)</td>
<td>4.3 (3.6, 5.0)</td>
<td>4.3 (3.7, 5.0)</td>
<td>4.2 (3.5, 4.9)</td>
<td>4.0 (3.5, 4.6)</td>
<td>0.755</td>
<td>0.211</td>
</tr>
</tbody>
</table>

All values are means (95% CI). P-values adjusted for sex and %BF

%BF: percentage body fat, AS: artificially-sweetened, CI: confidence interval, HDL-C: high density lipoprotein cholesterol, LDL-C: low density lipoprotein cholesterol, n: number, ORI: obesity resistant individuals, ORI/AS: obesity resistant individuals who consumed the artificially-sweetened beverage, ORI/SS: obesity resistant individuals who consumed the sugar-sweetened beverage, OSI: obesity susceptible individuals, OSI/AS: obesity susceptible individuals who consumed the artificially-sweetened beverage, OSI/SS: obesity susceptible individuals who consumed the sugar-sweetened beverage, SS: sugar-sweetened, TAG: triacylglyceride, TC: total cholesterol, TC:HDL: total cholesterol to high density lipoprotein ratio
4.3.5 Beverage Use Questionnaire

Table 4.6 shows the proportion of ORI and OSI consuming either the SS or AS beverage responding positively to the statements regarding the use of the study beverages during the 8-week intervention. Percentage and number of participants with a positive response are presented. For the majority of the statements, there was no evidence of an interaction between ORS category and the intervention.

Obesity susceptible individuals (OSI) randomly assigned to consume the artificially-sweetened (AS) beverage (OSI/AS) were significantly less likely to report they ‘continued to drink as they normally would and usually drank the study beverage as an extra drink’ than ORI/AS (P=0.005) and OSI/SS (P=0.034). Participants in the ORI/SS group were also significantly less likely to report they ‘continued to drink as they normally would and usually drank the study beverage as an extra drink’ than ORI/AS (P=0.032). Participants in the OSI/AS group were significantly more likely to report they usually drank the study beverage ‘sipped throughout the day’ compared to OSI/SS (P=0.010). Finally, OSI/SS were significantly less likely to report they usually drank the study beverage ‘around lunchtime’ than ORI/AS (P=0.033) and OSI/AS (P=0.033).

4.3.6 Cross-Sectional Study 1: Eating Behaviour

A cross-sectional analysis of eating behaviour was undertaken in the IceT cohort using the Dutch Eating Behaviour Questionnaire (DEBQ) and the Intuitive Eating Scale (IES).

4.3.6.1 Dutch Eating Behaviour Questionnaire (DEBQ)

Results of the Dutch Eating Behaviour Questionnaire (DEBQ) are presented in Table 4.7. Mean responses for restrained eating, emotional eating and external eating and 95% CI are presented. The estimated differences and P-values are presented for sex adjusted for ORS category and for ORS category adjusted for sex. Further adjustment for %BF is also presented.
### Table 4.6. Proportion of responses regarding beverage use of obesity resistant individuals (ORI) and obesity susceptible individuals (OSI) following 8 weeks of daily consumption of a sugar-sweetened (SS) beverage (1000 kJ) compared to an artificially-sweetened (AS) beverage (25 kJ)

<table>
<thead>
<tr>
<th>Statement</th>
<th>SS Beverage</th>
<th>AS Beverage</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>ORI</td>
<td>OSI</td>
<td>ORI</td>
</tr>
<tr>
<td>n</td>
<td>30</td>
<td>27</td>
<td>33</td>
</tr>
<tr>
<td>I usually drank the Ice Tea instead of a drink I would normally have consumed</td>
<td>60.0 (18)</td>
<td>33.0 (9)</td>
<td>36.4 (12)</td>
</tr>
<tr>
<td>I usually drank the Ice Tea instead of food I would normally have consumed</td>
<td>3.3 (1)</td>
<td>11.1 (3)</td>
<td>3.0 (1)</td>
</tr>
<tr>
<td>I continued to drink as I normally would and usually drank the Ice Tea as an extra drink</td>
<td>36.7 (11)abc</td>
<td>55.6 (15)ab</td>
<td>63.6 (21)b</td>
</tr>
<tr>
<td>I continued to eat as I normally would and usually drank the Ice Tea as an extra</td>
<td>63.3 (19)</td>
<td>63.0 (17)</td>
<td>69.7 (23)</td>
</tr>
<tr>
<td>I usually drank the Ice Tea: as part of a main meal</td>
<td>16.7 (5)</td>
<td>14.8 (4)</td>
<td>18.2 (6)</td>
</tr>
<tr>
<td>quickly (in less than 15 min)</td>
<td>43.3 (13)</td>
<td>44.4 (12)</td>
<td>48.5 (16)</td>
</tr>
<tr>
<td>slowly (over a period of 15 min to 1 hour)</td>
<td>36.7 (11)</td>
<td>51.9 (14)</td>
<td>36.7 (12)</td>
</tr>
<tr>
<td>sipped throughout the day</td>
<td>20.0 (6)abc</td>
<td>0b</td>
<td>15.2 (5)abc</td>
</tr>
<tr>
<td>in the morning</td>
<td>30.0 (9)</td>
<td>37.0 (10)</td>
<td>24.2 (8)</td>
</tr>
<tr>
<td>around lunchtime</td>
<td>46.7 (14)ab</td>
<td>14.8 (4)b</td>
<td>51.5 (17)a</td>
</tr>
<tr>
<td>in the early afternoon</td>
<td>16.7 (5)</td>
<td>29.6 (8)</td>
<td>30.3 (10)</td>
</tr>
<tr>
<td>in the late afternoon</td>
<td>26.7 (8)</td>
<td>22.2 (6)</td>
<td>27.3 (9)</td>
</tr>
<tr>
<td>around dinnertime</td>
<td>20.0 (6)</td>
<td>7.4 (2)</td>
<td>24.2 (8)</td>
</tr>
<tr>
<td>in the early evening</td>
<td>10.0 (3)</td>
<td>14.8 (4)</td>
<td>9.1 (3)</td>
</tr>
</tbody>
</table>

All values are percentage (n); * indicates Fisher’s Exact test, all others Chi-square test. When the overall P-values <0.05, pairwise comparisons were performed. Values with different superscript letter indicate significant differences P<0.05. AS: artificially-sweetened, n: number, ORI: obesity resistant individuals, OSI: obesity susceptible individuals, SS: sugar-sweetened.
### Table 4.7. Scores for the Dutch Eating Behaviour Questionnaire (DEBQ) for obesity resistant individuals (ORI) and obesity susceptible individuals (OSI)

<table>
<thead>
<tr>
<th></th>
<th>ORI</th>
<th>OSI</th>
<th>Estimated difference between ORI and OSI adjusted for sex (95%CI)</th>
<th>P-value for sex (adjusted for ORS category)</th>
<th>P-value for ORS category (adjusted for sex)</th>
<th>Estimated difference between ORI and OSI adjusted for sex (95%CI)</th>
<th>P-value for sex (adjusted for ORS category)</th>
<th>*P-value for sex (adjusted for ORS category)</th>
<th>*P-value for sex (adjusted for ORS category)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Females (27)</td>
<td>Males (32)</td>
<td>Females (26)</td>
<td>Males (22)</td>
<td></td>
<td>Females (26)</td>
<td>adjusted for sex (95%CI)</td>
<td>P-value for sex (adjusted for ORS category)</td>
<td>P-value for ORS category (adjusted for sex)</td>
</tr>
<tr>
<td>Restrained Eating</td>
<td>20.8 (17.2, 23.36)</td>
<td>16.4 (13.9, 18.8)</td>
<td>30.5 (27.9, 33.2)</td>
<td>28.0 (25.9, 30.1)</td>
<td>10.9 (8.4, 13.5)</td>
<td>0.011</td>
<td>&lt;0.001</td>
<td>10.8 (7.9, 13.7)</td>
<td>0.039</td>
</tr>
<tr>
<td>Emotional Eating</td>
<td>27.3 (23.3, 31.3)</td>
<td>21.2 (17.3, 25.0)</td>
<td>32.4 (28.0, 36.8)</td>
<td>28.8 (25.4, 32.1)</td>
<td>6.3 (2.4, 10.2)</td>
<td>0.011</td>
<td>0.002</td>
<td>5.8 (4.1, 10.2)</td>
<td>0.056</td>
</tr>
<tr>
<td>External Eating</td>
<td>23.8 (22.0, 25.6)</td>
<td>23.8 (22.0, 25.2)</td>
<td>24.5 (22.4, 26.7)</td>
<td>23.7 (22.1, 25.4)</td>
<td>0.4 (-1.3, 2.2)</td>
<td>0.612</td>
<td>0.625</td>
<td>0.4 (-1.5, 2.4)</td>
<td>0.660</td>
</tr>
</tbody>
</table>

All values are means (95%CI). *P-values adjusted for %BF. %BF: percentage body fat; CI: confidence interval, DEBQ: Dutch Eating Behaviour Questionnaire, n: number, ORI: obesity resistant individuals, ORS: obesity resistance/susceptibility, OSI: obesity susceptible individuals.
Obesity resistant individuals (ORI) reported significantly lower scores for restrained eating and emotional eating compared to OSI (both P≤0.002). These differences remained significant following adjustment for %BF (both P≤0.010). No differences were observed in scores for external eating between ORI versus OSI. Significantly higher scores for restrained eating and emotional eating were observed in female compared to male participants. The difference in restrained eating scores remained significant after controlling for %BF, but the difference in emotional eating disappeared. There were no differences in external eating in females versus males.

4.3.6.2 Intuitive Eating Scale (IES)

Table 4.8 shows results from the Intuitive Eating Scale (IES) in ORI compared to OSI. Mean responses for total intuitive eating score and scores for the three subscales and 95% CI are presented. The estimated differences and P-values are presented for sex adjusted for ORS category and for ORS category adjusted for sex. Further adjustment for %BF is also presented.

There was a significant difference between ORI and OSI for all three subscales and the total intuitive eating score with and without adjustment for %BF (all P≤0.002). Obesity resistant individuals (ORI) had significantly higher scores for the ‘unconditional permission to eat’ (a readiness to eat in response to internal physiological hunger signals and the food that is desired at the moment) subscale, the ‘eating for physical rather than emotional reasons’ subscale, the ‘reliance on internal hunger/satiety cues’ subscale and the total intuitive eating score. After adjustment for %BF a borderline significant difference was observed between females and males for the ‘eating for physical rather than emotional reasons’ subscale, with female participants reporting lower scores (P=0.05). No differences were seen in the remaining two subscales or the total intuitive eating score in females compared to males.
<table>
<thead>
<tr>
<th></th>
<th>ORI</th>
<th></th>
<th>OSI</th>
<th></th>
<th>Estimated difference between ORI and OSI adjusted for sex and %BF</th>
<th>95%CI</th>
<th>*P-value for ORI category (adjusted for sex)</th>
<th>95%CI</th>
<th>P-value for sex (adjusted for ORI category)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unconditional permission to eat subscale</td>
<td>Females 30</td>
<td>3.8 (3.6, 3.9)</td>
<td>Males 33</td>
<td>3.9 (3.6, 4.1)</td>
<td>-1.0 (1.2, -0.8)</td>
<td>0.522</td>
<td>0.001</td>
<td>-1.0 (1.3, -0.8)</td>
<td>0.572</td>
</tr>
<tr>
<td>Eating for physical rather than emotional reasons subscale</td>
<td>Females 28</td>
<td>3.6 (3.4, 3.9)</td>
<td>Males 25</td>
<td>3.7 (3.4, 4.0)</td>
<td>-1.0 (1.2, -0.8)</td>
<td>0.522</td>
<td>0.001</td>
<td>-1.0 (1.3, -0.8)</td>
<td>0.572</td>
</tr>
<tr>
<td>Reliance on internal hunger/satiation cues subscale</td>
<td>Females 28</td>
<td>3.6 (3.6, 3.9)</td>
<td>Males 25</td>
<td>3.7 (3.4, 3.9)</td>
<td>-1.0 (1.2, -0.8)</td>
<td>0.522</td>
<td>0.001</td>
<td>-1.0 (1.3, -0.8)</td>
<td>0.572</td>
</tr>
<tr>
<td>Total intuitive eating score</td>
<td>Females 30</td>
<td>3.8 (3.6, 3.9)</td>
<td>Males 33</td>
<td>3.9 (3.6, 4.1)</td>
<td>-1.0 (1.2, -0.8)</td>
<td>0.522</td>
<td>0.001</td>
<td>-1.0 (1.3, -0.8)</td>
<td>0.572</td>
</tr>
</tbody>
</table>

All values are means (95%CI). *Estimated difference between ORI and OSI adjusted for sex (95%CI). **P-values are for sex (adjusted for ORI category).
4.3.7 Cross-Sectional Study 2: Sensitivity to Oral Fatty Acid Ingestion

4.3.7.1 Participant Characteristics
A sub-sample of 86 participants (50 ORI and 36 OSI) were recruited from the IceT study cohort for a cross-sectional assessment of sensitivity to oral fat ingestion. The characteristics of this sub-sample are presented in Table 4.9. Obesity resistant individuals were significantly younger, taller, and had a lower BW, BMI, waist circumference and %BF than OSI.

Table 4.9. Characteristics of a subsample of obesity resistant individuals (ORI) and obesity susceptible individuals (OSI) who undertook an assessment of sensitivity to oral fatty acid ingestion

<table>
<thead>
<tr>
<th></th>
<th>ORI</th>
<th></th>
<th></th>
<th>OSI</th>
<th></th>
<th></th>
<th>*P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Females</td>
<td>Males</td>
<td>Females</td>
<td>Males</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>N</td>
<td>24</td>
<td>26</td>
<td>20</td>
<td>16</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Age (y)</td>
<td>27.1 (6.5)</td>
<td>29.3 (8.9)</td>
<td>31.2 (9.1)</td>
<td>38.5 (12.2)</td>
<td>0.002</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Height (m)</td>
<td>1.69 (0.06)</td>
<td>1.79 (0.07)</td>
<td>1.63 (0.06)</td>
<td>1.75 (0.06)</td>
<td>&lt;0.001</td>
<td></td>
<td></td>
</tr>
<tr>
<td>BW (kg)</td>
<td>58.7 (7.6)</td>
<td>71.4 (10.2)</td>
<td>70.3 (20.6)</td>
<td>88.8 (10.9)</td>
<td>&lt;0.001</td>
<td></td>
<td></td>
</tr>
<tr>
<td>BMI (kg.m²)</td>
<td>20.6 (2.1)</td>
<td>22.3 (2.5)</td>
<td>26.4 (6.7)</td>
<td>29.1 (2.8)</td>
<td>&lt;0.001</td>
<td></td>
<td></td>
</tr>
<tr>
<td>WC (cm)</td>
<td>68.3 (4.7)</td>
<td>78.8 (7.4)</td>
<td>79.7 (15.6)</td>
<td>95.2 (7.4)</td>
<td>&lt;0.001</td>
<td></td>
<td></td>
</tr>
<tr>
<td>%BF</td>
<td>26.9 (6.6)</td>
<td>16.5 (6.5)</td>
<td>35.2 (11.4)</td>
<td>27.6 (7.3)</td>
<td>&lt;0.001</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

All values are means (SD), *P-values from regression analysis for ORS category adjusted for sex

4.3.7.2 Sensitivity to Oral Fatty Acid Ingestion
Table 4.10 shows the results of the triplicate triangle tests conducted on ORI and OSI to assess hypo- and hypersensitivity to oral fatty acid ingestion. Of the 86 participants who took part in this assessment, 53 participants (62% total, 56% ORI and 69% OSI) were defined as hyposensitive and 33 participants (38% total, 44% ORI and 31% OSI) as hypersensitive. In the unadjusted model, there was no difference in the odds of being hypersensitive to fatty acids between ORI and OSI (OR=1.79, 95%CI: 0.72, 4.40; P=0.208). Confounding variables were added as follows with all these models showing significantly higher odds of being
<table>
<thead>
<tr>
<th></th>
<th>0 out of 3</th>
<th>1 out of 3</th>
<th>2 out of 3</th>
<th>Total Hyposensitive ≤2 out of 3</th>
<th>Total Hypersensitive 3 out of 3</th>
<th>*Adjusted Odds Ratio (95%CI)</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>ORI</td>
<td>7 (14)</td>
<td>10 (20)</td>
<td>11 (22)</td>
<td>28 (56)</td>
<td>22 (44)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>OSI</td>
<td>4 (11)</td>
<td>8 (22)</td>
<td>13 (36)</td>
<td>25 (69)</td>
<td>11 (31)</td>
<td>3.6 (1.11, 11.79)</td>
<td>0.034</td>
</tr>
<tr>
<td>Total</td>
<td>11 (13)</td>
<td>18 (21)</td>
<td>24 (28)</td>
<td>53 (62)</td>
<td>33 (38)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Odds of being hypersensitive to oral fatty acids (ORI vs. OSI) calculated using multiple logistic regression adjusted for sex, age, and %BF
%BF: percentage body fat, CI: confidence interval, ORI: obesity resistant individuals, OSI: obesity susceptible individuals
hypersensitive amongst ORI compared to OSI: %BF (OR:3.50, 95%CI: 1.14, 10.79; P=0.029), then age (OR=4.02, 95%CI: 1.22, 13.27; P=0.022), and finally sex (OR=3.60, 95%CI: 1.11, 11.79; P=0.034) (Table 4.10). All three adjusted models produced similar interpretations and all model diagnostics indicated a lack of issues around goodness of fit despite the last model (%BF, age and sex) going slightly beyond the goal of one predictor per 10 non-events and 10 events.

4.3.7.3 Fat Ranking
A total of 53% (46% ORI and 64% OSI) of the cohort scored 0, 35% (36% ORIs and 31% OSIs) scored between 1 and 4, and only 12% (16% ORIs and 6% OSIs) of the cohort scored 5. There was evidence of overdispersion for all models and so negative binomial regression was used in preference to Poisson regression. There was a non-statistically significantly raised rate of scores for ORIs compared to OSIs (IRR=1.59, 95% CI: 0.80, 3.17; P=0.186) with interpretation unaffected after adding age (IRR=2.04, 95% CI: 0.99, 4.21; P=0.053), then BMI (IRR=1.53, 95% CI: 0.63, 3.71; P=0.348), and finally height (IRR=1.29, 95% CI: 0.50, 3.29; P=0.600).
4.4 Discussion

The IceT study was comprised of three parts:

1. A randomised, placebo-controlled, double-blind parallel intervention study investigating comparing the capability of ORI and OSI to compensate for additional beverage calories.
2. A cross-sectional study investigating eating behaviour amongst ORI compared to OSI.
3. A cross-sectional study investigating sensitivity to oral fatty acid ingestion amongst ORI compared to OSI.

4.4.1 The IceT Study Intervention

Previous studies have shown large inter-individual variation in weight gain in response to overfeeding [412]. This was demonstrated in the seminal work by Sims and colleagues [415-417] in the Vermont Prison Overfeeding Study, and more recently by the Swedish Fast Food Study Group [418]. The ability to compensate for the ingestion of excess calories may be an adaptive response that protects obesity resistant individuals from weight gain. To examine whether differences exist between ORI and OSI in their capability to compensate for additional calories, participants in the IceT study were randomly assigned to receive either a 500 ml SS beverage (~1000 kJ) or a 500 ml AS beverage (~25 kJ) daily for 8 weeks. The primary outcome of interest was energy balance and change in BW over the 8 week period.

As far as the candidate is aware the IceT study intervention is the longest overfeeding study that has been conducted in participants specifically defined as obesity resistant or obesity susceptible and the only one utilising a randomised, placebo-controlled, double-blind, parallel intervention protocol. The majority of previous investigations published within the obesity resistance literature have involved short-term (1-3 days) overfeeding compared to eucaloric and/or underfeeding conditions [26, 30-32, 34, 80, 82]. Due to the short duration of these studies, they are unable to provide any information on the impact of energy manipulation on weight control. Only one other study has attempted to assess the
longer-term impact of overfeeding additional calories on weight control within the obesity resistance literature. Using a single intervention, Germain and colleagues [25] investigated the impact of 4 weeks of fat overfeeding on BW in 8 female constitutionally thin individuals (CTI) compared to 8 normal BMI individuals. The BW of the normal BMI individuals increased significantly from baseline (+0.725kg) with overfeeding, whereas no significant differences were observed in the BW of CTI at the end of the 4 week period (+0.225kg). Unfortunately between group comparisons were not undertaken so it is unknown if there was any difference in the response of CTI and controls to the intervention. A major limitation of this study was the single intervention design that lacked randomisation.

In contrast to the findings of Germain et al [25], both the ORI and OSI participants in the IceT study showed a significant increase in BW following 8 weeks of consumption of the SS beverage compared to the AS beverage. Concomitant significant increases in BMI, WC and %BF were also observed after consumption of the SS compared to the AS beverage. However, the lack of evidence of an interaction between the ORS category and the intervention for any of the body composition variables, suggests ORI and OSI did not respond differently to the intervention.

This finding was somewhat unexpected and if taken at face value, would suggest that ORI and OSI do not differ in their ability to compensate for the ingestion of additional calories. According to the Pennington Biomedical Research Center calculator [462] a 1000 kJ increase in energy intake per day would result in a weight gain of 2.9 – 3.2 kg in ORI and around 2.6 kg in OSI after an 8 week period. As ORI only gained 0.9 kg and OSI only 0.8 kg over the 8 week period, it would suggest that some compensation for the additional calories did occur in both groups. The mechanism responsible for facilitating this compensation is unknown.

Participants in both groups could have potentially compensated for the extra dietary energy intake by increasing PA. This would seem unlikely as no significant differences were observed in the PA levels of ORI compared to OSI from baseline to 8 weeks. However, the pedometers used in the IceT study were only able to assess
physical activity in terms of number of steps taken and total activity time spent at or above moderate intensity. The compensatory mechanisms could be the result of changes in light intensity PA or sedentary behaviour, which the pedometers were unable to measure.

In response to the additional 1000 kJ ingested per day for 8 weeks from the SS beverage, participants in the IceT study may have altered the amount of energy consumed from other sources within the diet. Unfortunately, the analysis of the 4DDRs was unable to be completed in time for submission of this thesis, so at this time it can only be speculated as to whether adjustments in energy intake were fully or partly responsible for the partial compensation that occurred in both groups.

The way in which participants incorporated the study beverage into their daily lives was very similar amongst the four treatment groups. For the majority of the statements in the beverage use questionnaire, there was no evidence of a difference between the four groups (i.e. ORS/SS, OSI/SS, ORI/AS, OSI/AS) for the proportion of participants indicating positive agreement. Compliance to the intervention was high with participants reporting consumption of 93% (OSI/AS) to 95.8% (OSI/SS) of the study beverages and no significant differences observed in compliance between the treatments. Therefore differences in compliance or the way in which the study beverages were consumed do not appear to be responsible for the results in the present study.

One likely reason why no significant differences were observed in the compensatory capabilities of ORI compared to OSI could be due to the vehicle used to deliver the additional calories. In the study conducted by Germain and colleagues [25], CTI and normal BMI controls were supplied with packages containing a fixed daily quantity of olive oil, peanuts, gruyere cheese and butter which provided an additional 2640 kJ.d⁻¹ over a four week period. As previously stated, the BW of the CTI at the end of this study was not significantly different from baseline measurements, whereas the BW of the normal BMI controls increased significantly. In contrast, a SS beverage was chosen as the vehicle to
deliver the additional calories to participants in the IceT study. It has been suggested that energy-containing beverages may elicit weaker satiety and compensatory dietary responses than solid food [216-218]. This potential difference in the ability to perceive calories from food compared to calories from fluids may be a reason why neither the ORI or the OSI were able to fully compensate for the additional calories supplied by the SS beverage in the IceT study.

The results of the IceT study intervention add to the growing body of evidence of the effects of SS beverages on BW. Available evidence to date from observational, prospective and intervention studies suggests an increased risk of weight gain and obesity with higher intakes of SS beverages [224] [189, 214, 221]. Although it appears some compensation for the liquid energy in SS beverages does occur [225], without full compensation there is the risk of gradual adiposity 'creep' and subsequent weight gain [189]. The finding of increased BW in both obesity resistant and obesity susceptible individuals after 8 weeks of daily SS beverage consumption, suggests neither group are immune to the potential insidious effects of SS beverages on weight control.

As the IceT study was a placebo-controlled double-blind study, the placebo needed to provide little to no calories and be indistinguishable from the active treatment. It would have been reasonably simple to find a solid food to act as the vehicle in the active treatment, but a very difficult undertaking to find a counterpart solid food to act as the placebo. Future studies would need to invest significant time and resources into developing an energy-containing solid food and it's equivalent non-energetic (or at least substantially lower-energy) placebo. Only then can a carefully controlled, randomised, double-blind study be undertaken to more clearly determine if any differences exist in the capabilities of individuals resistant to obesity compared to those susceptible to obesity to compensate for additional calories.

In summary, although the consumption of a SS beverage, which provided around 1000 kJ.d⁻¹, increased BW compared to the consumption of a low calorie
alternative, there was no evidence of a difference between those resistant or susceptible to obesity. This lack of difference in the compensation capabilities of ORI compared to OSI may indicate that ORI are no better at compensating for additional calories as we had hypothesised or the result may have been influenced by the choice to use a fluid as the vehicle to deliver the additional calories rather than a solid food. Future studies need to address this limitation by selecting food-based vehicles as the active treatment and placebo.

4.4.2 Cross-Sectional Study 1: Eating Behaviour
Significant differences in restrained eating and disinhibition amongst ORI compared to OSI, as measured by the Three-factor Eating Questionnaire (TFEQ), were identified in the B2BL study. In light of these findings, further investigation of potential differences in other eating behaviour constructs was undertaken using the IceT study cohort. Specifically, the DEBQ was used to assess restrained eating, emotional eating and external eating, while the IES was used to assess intuitive eating amongst individuals resistant and susceptible to obesity. Significant differences between ORI and OSI were observed in all the eating behaviour constructs under investigation, with the exception of external eating.

4.4.2.1 The Dutch Eating Behaviour Questionnaire (DEBQ)
The finding of lower levels of restrained eating in ORI compared to OSI in the present study is in agreement with the only other study published within the obesity resistance literature that utilised the DEBQ to assess restrained eating. Germain and colleagues [25] reported lower restrained eating in female CTI compared to normal BMI controls. Unfortunately results for the emotional eating and external eating subscales of the DEBQ were not reported for this study. The results from the IceT study confirm those observed in the B2BL study where dietary restraint (and disinhibition) were significantly lower in ORI compared to OSI. Taken together the results from both studies strengthen the proposal that by exhibiting lower restrained eating and disinhibition, ORI may be afforded some protection against overeating and the potential associated weight gain.
Emotional eating refers to the tendency to overeat in response to negative emotions as a result of poor interoceptive awareness [352]. The obesity resistant participants in the IceT study reported lower levels of emotional eating than the obesity susceptible participants. This is in line with results from previous prospective studies in which individuals with high scores for emotional eating appear to be at increased risk of becoming overweight/obese [352, 356-358].

External eating is overeating in response to external food-related cues in the immediate environment i.e. the sight, smell and taste of attractive foods, regardless of internal feelings of hunger and satiety [369]. In contrast to restrained eating and emotional eating, no significant differences were observed in the level of external eating exhibited by ORI versus OSI in the present study. This result is supported by evidence from cross-sectional studies that have observed no difference in the degree of external eating between overweight and normal weight people [357, 371-375] and prospective studies that tend to show external eating may not be a good predictor of BMI change [352, 356, 358]. It has been suggested the reason for this lack of difference may be because the DEBQ is unable to differentiate between two proposed types of external eating cues – normative and sensory [376]. In this model, Herman & Polivy [376] argue that normative cues (environmental indicators of how much one should eat) affect all eaters indiscriminately, whereas sensory cues (properties of the food itself) have a stronger effect in certain people i.e. the obese, dieters and hungry individuals.

The DEBQ is only able to examine external eating behaviours at the individual level. No examination of the social or environmental factors that may influence external eating was undertaken in the present study. It is possible that these factors and the resulting influence on external eating behaviours may differ amongst ORI compared to OSI. For instance, ORI may have more supportive social environments (e.g friends/family that eat well), and therefore there is less exposure to environments of temptation. Similarly, ORI may live in households where tempting foods are not purchased, again resulting in lower exposure to opportunities to be tempted by attractive foods. Investigation of these social and
environmental influences could form part of future studies comparing the characteristics of ORI and OSI.

4.4.2.2 The Intuitive Eating Scale (IES)

Intuitive eating is an adaptive eating style to regulate food intake that is based on physiological hunger and satiety cues rather than situational and emotional cues [310, 377]. The three original subscales of the IES (Unconditional Permission to Eat, Eating for Physical Rather Than Emotional Reasons, and Reliance on Hunger and Satiety Cue) and total intuitive eating were assessed amongst ORI compared to OSI in the present study. Obesity resistant participants reported higher scores for total intuitive eating and all three of the subscales compared to obesity susceptible individuals. To the best of the candidate's knowledge, this is the first study to compare intuitive eating in individuals specifically classified into these two ORS categories. The results, however, are in line with other cross-sectional studies that indicate intuitive eaters have a lower BMI than non-intuitive eaters [377, 379, 382].

In summary, individuals resistant to obesity appear to exhibit more healthful eating behaviours than obesity susceptible individuals i.e. they engage in less restrained and emotional eating, and are more intuitive eaters. The expression of such behaviours may form part of the reason why ORI are better able to manage their BW in the current obesogenic environment. In light of the results from the present study, it would seem plausible that incorporation of eating behaviour modification/retraining into weight control interventions may be useful in reducing the susceptibility of some individuals to obesity. An intervention strategy of this type would first need to be examined in a randomised, controlled trial to ascertain the success and value of retraining eating behaviours amongst OSI, before incorporation into community or population weight management programmes.
4.4.3 Cross-Sectional Study 2: Sensitivity to Oral Fatty Acid Ingestion

Hypersensitivity to fat may be one mechanism that allows some individuals to better regulate their BW by reducing their preference for high fat foods and the potential for overconsumption [122]. The oral sensitivity to oleic acid and ability to rank the fat content of custard samples was compared in a sub-sample of ORI and OSI from the IceT study cohort. After adjustment for potential confounders, the odds of being hypersensitive to oral fatty acids was over three times higher amongst ORI compared to OSI. However, there was no evidence of an association between obesity resistance and the ability to detect differences and rank the levels of fat in a common food.

Previous studies have reported a negative association between fat sensitivity and BMI [122-124]. However, as far as can be ascertained, this is the first study to compare oral fatty acid sensitivity and evaluate the ability to rank fat in a food in individuals resistant to obesity compared to individuals susceptible to obesity. Although no human studies have previously compared these two groups, our findings are in agreement with an animal study which reported fatty acid sensitivity varied significantly between diet-induced obesity prone and diet-induced obesity resistant rats [489].

Fat sensitive people have been shown to have a lower preference for high fat foods or a lower fat intake by several researchers [122, 123, 490]. Since an acquired preference for high fat foods has been associated with obesity [121], the finding of a higher sensitivity to fat amongst ORI compared to OSI in the present study may indicate that ORI are more likely to reject high fat foods. However, in the B2BL study no significant differences were observed in fat intake amongst ORI and OSI. Larger studies assessing diet over a longer period are needed to examine this relationship. Conversely, the lower sensitivity amongst OSI may mean they are more likely to accept and consume higher fat foods, as was observed by Blundell and colleagues [76] where those participants susceptible to obesity had a higher preference for high fat foods. The findings from the present study should be considered in light of the further observations that there is large inter-individual
variability in perceived intensity [491] and threshold [492] for fatty acid. In addition, it is important to note that the assessment of sensitivity to oral fatty acid ingestion and the fat ranking test was conducted in a controlled setting. The response of ORI and OSI to f

In summary, ORI appear to have a higher sensitivity to oral fat ingestion than OSI. This hypersensitivity to fat may be one mechanism that assists ORI to maintain a healthy BW. However, despite this finding for fat sensitivity, there was no evidence for ORI to be better at ranking fat levels in a common food (custard). If indeed ORI, who appear more sensitive to fat, have reduced preference for high fat foods, their ability to detect different fat levels remains unclear. This could be addressed in future studies by assessing the fat ranking ability of ORI using a number of different foods. In addition, it is important to note that the fat ranking assessment was conducted in a controlled setting. While ORI may not be able differ in their ability to rank the fat content of a custard compared to OSI, under free-living conditions they likely know what they are eating and may make active decisions to choose lower fat/‘healthier’ options. Future research could also investigate the effects of changing fat sensitivity amongst those susceptible to obesity. Results of a recent study indicate recalibration of fat sensitivity is possible [493]. Stewart and colleagues [493] observed increased fatty acid sensitivity among both lean and overweight participants after four weeks consuming a low fat diet. The long-term maintenance of such recalibrations would be important considerations for interventions using this approach to try and improve weight management.

**4.4.4 Strengths and Limitations**

Following on from the B2BL study, the IceT study was designed to assess a number of gaps in the literature. It was the first study to investigate the ability of specifically defined obesity resistant versus obesity susceptible individuals to compensate for additional calories using a randomised placebo-controlled double-blind parallel study design. It was also the first study to assess intuitive eating and to report results from all three subscales of the DEBQ in ORI compared to OSI.
Finally, it was also the first study to assess and compare the sensitivity to oral fatty acid ingestion and the ability to rank fat in food in these two ORS categories.

As with the B2BL study, body composition in the IceT study intervention was assessed using DXA scans. A precise and accurate measure of body composition was needed to be able to detect the small differences in fat mass and LBM that were likely to occur with small changes in BW. Other body composition methods such as bioelectric impedance or skinfold thicknesses lack the sensitivity required for this assessment [482].

A major strength of the IceT study intervention was the excellent retention rate and high compliance with the study treatments. Of the 118 participants allocated to the four treatment groups in the study, 116 (98.3%) completed the study and were included in the final analysis. One participant withdrew from the study for personal reasons and 1 participant was excluded from the analysis as they began a weight loss programme during the study and this violated the exclusion criteria for the study (see Fig 4.1). In addition compliance with the study treatments was high with participants reporting consumption of ≥ 93% of the study beverages in the four treatment groups. One reason why compliance was high in the present study was most likely due to participants being regularly supplied with the study beverages. In addition, if participants were unable to collect the beverages themselves, a home delivery was arranged.

All study documents were made as participant-friendly as possible by employing simple and clear layouts. To ensure participants understood all the study procedures and what was required of them, clear instructions were provided both verbally and in a written format. As with the B2BL study, all study data was double-entered to limit transcription errors.

Interpretation of the results of the IceT study should be considered in light of the following limitations. Firstly, as previously discussed, the use of fluids as opposed to solid food as the treatment and placebo vehicles in the IceT study intervention has some implications. The calories in energy-containing beverages may not be
perceived to the same extent as calories from solid food [216-218] and this may have impacted on the effectiveness of the study to detect differences in the capability of obesity resistant compared to obesity susceptible participants to compensate for additional calories. The sample size may have been insufficient to detect small but meaningful interactions between ORS categories and the intervention. This is because substantial weight gain can accumulate over time from relatively small imbalances in energy regulation.

As previously discussed, in relation to interpretation of results from the B2BL study, limitations in the screening tool used to classify ORI and OSI may have contributed to the lack of difference capability to compensate for additional calories between the two groups. The heterogeneous obesity susceptible group (consisting of individuals who are currently overweight/obese, overweight/obese individuals who have undergone weight loss and healthy weight individuals who put considerable effort into avoiding weight gain) may have responded in more variable ways compared to the more homogeneous obesity resistant group. Such variability in responses would make it harder to detect differences between the obesity resistant and obesity susceptible groups.

Using a protocol very similar to the B2BL study, dietary intake data was collected at baseline and at the end of the 8 week IceT study intervention via 4DDR. Utilising this method ensures information on actual intake could be collected at the time of consumption on both week days and a weekend day. Unfortunately, the diet record analysis could not be completed in time for submission of this thesis, so information on whether compensation for additional calories occurred with the diet is unavailable at this time.

Due to equipment constraints, pedometers rather than accelerometers were used to assess potential changes in PA during the IceT study. No significant differences in PA were found from baseline to end of the eight week period between any of the four treatment groups, however, as previously mentioned the pedometers were only able to measure as small number of PA outcomes i.e. number of steps and total activity time spent at or above moderate intensity. Potential differences in
time spent engaging in sedentary behaviour and light intensity (usually the largest components of PA) were unable to be accounted for using this assessment tool.

The cross-sectional design of the eating behaviour and sensitivity to oral fatty acid ingestion studies means that causality cannot be ascertained as the association between variables has only been assessed at one time point, but these analyses are useful for developing hypotheses.

As with the B2BL study, the questionnaires used in the IceT study were self-administered. This may have the advantage of encouraging participants to answer the questions more honestly compared to an interview situation, but this design also means the questions are potentially open to different interpretations. The IceT study cohort was an ethnically diverse group with participants identifying with 16 different ethnic backgrounds. The majority of the cohort (73.2%) identified as having an ethnic background where it is likely English was a first language. However, this means that 26.7% (31 out of 116 participants included in the final analysis) identified with an ethnic background where it is likely English was a second language. This may have affected the way these participants interpreted the study questionnaires as these were all presented in English.

A limitation of the sensitivity to oral fatty acid cross-sectional study was that we classified participants as hyper- and hyposensitive to 1.4 mM of oleic acid, rather than performing a threshold test using a range of concentrations. This concentration was selected based on the results of several studies among participants living in similar environments to those in the IceT study [123, 494].

Although many participants were recruited from emails sent to University of Otago staff and students, the socio-economic status (education level, occupation, income etc) of the study population is unknown. The socio-economic status of participants may have potentially influenced the results of this study or their interpretation.
5 Conclusion

5.1 Conclusion
Despite the number of individuals who are overweight or obese surpassing the 2 billion mark globally, a reasonable proportion of the population remain lean, seemingly resistant to the current obesogenic environment. Important differences must exist between these obesity resistant individuals (ORI) and those who struggle to maintain a healthy body weight (BW). Investigating the characteristics of ORI offers an alternative approach to determine the cause, treatment and prevention of obesity. Genetics undoubtedly play a role, but investigating potential variation in the genetic make-up of individuals resistant or susceptible to obesity was beyond the scope of this thesis. Furthermore, as genetics is non-modifiable, investigation of genetics may be less informative for developing public health strategies to assist obesity susceptible individuals (OSI).

For this thesis a comprehensive cross-sectional study investigating multiple variables in specifically defined ORI and OSI was undertaken to elucidate if, and what, differences may exist physiologically, metabolically, behaviourally and/or in terms of lifestyle between these two groups self-identifying as obesity resistant and obesity susceptible. A randomised, placebo-controlled, double-blind, parallel study, the first of its kind, was also conducted to assess the long-term capability of ORI versus OSI to compensate for additional dietary energy in the form of a beverage.

The results of the cross-sectional studies in this thesis indicate there are some measurable differences in characteristics of ORI compared to OSI. As expected, based on differences in the body composition of the two groups, absolute resting metabolic rate (RMR) was higher in OSI versus ORI. The finding of a lower RMR relative to BW in OSI compared to ORI is perhaps of more interest because previous literature would suggest that when body composition is taken into account RMR is similar across the population [135, 136]. Obesity susceptible individuals are a group who report having to consume small amounts of food to
manage their weight. The lower RMR relative to BW in OSI compared to ORI provides some confirmation of this perception. Female OSI exhibited the lowest RMR relative to BW compared to all other groups. Although relatively small on a daily basis (+25.2 kJ.kg⁻¹.d⁻¹ compared to female ORI) this difference represents the potential for substantial weight gain in the longer term if compensatory behaviours are not implemented.

Commonly used prediction equations overestimated the RMR of male ORI and OSI to some extent, but especially for female OSI. This is a potential issue for female OSI using self-monitoring dietary-intake apps for weight loss or following planned energy-restriction programmes prescribed during nutrition counseling, as the weight loss targets may be impossible to achieve using the energy requirements over-estimated by these prediction equations. It is difficult to overcome this issue for individuals using self-monitoring dietary-intake apps, but identification of OSI prior to implementation of planned energy restriction in a nutrition counseling setting could allow a potentially lower energy requirement to be factored in for these clients/patients.

Individuals resistant to obesity seem to exhibit more healthful eating behaviours than OSI. They eat more intuitively and engage in less restrained and emotional eating and less disinhibition. Engagement in more healthy eating behaviours may be one of the reasons why ORI are better able to manage their BW in the current obesogenic environment. There is some evidence from clinical studies that completion of an intuitive eating programme can result in weight maintenance and potentially weight loss if the follow-up is longer than 18 months [379]. Therefore, incorporating eating behaviour retraining into weight control interventions may prove useful in reducing the obesity susceptibility of some individuals.

Another mechanism that may assist ORI to maintain a healthy BW while living in an obesogenic environment is a higher sensitivity to oral fatty acid ingestion. The odds of being hypersensitive to oral fatty acid ingestion was over three times higher amongst ORI compared to OSI. This higher sensitivity to fat may indicate ORI have a lower preference for high fat foods as has been shown in previous
studies [122, 123, 490], providing ORI with some protection against obesity. However, although ORI appear more sensitive to fat, there was no evidence that ORI were better at ranking fat levels in custard samples, so their ability to detect different fat levels remains unclear. This may be clarified by assessing fat ranking in a variety of different foods. As with eating behaviour, there is some evidence that sensitivity to fat can be modified by consuming a low fat diet [493]. Therefore, interventions aimed at achieving recalibration of fat sensitivity may also have some merit as a strategy to aid those who continually struggle with maintaining a healthy BW.

No differences were observed between ORI and OSI for a number of the other characteristics that were assessed and in some cases this was unexpected. Ghrelin concentrations were similar in both study groups despite differences in BW. Whether this indicates that OSI respond differently to the same ghrelin concentration, or conversely, that the lower than expected fasting ghrelin levels observed in the ORI provide a protective mechanism enabling these individuals to remain lean, requires further clarification.

There were very few differences observed for any of the dietary intake, physical activity (PA) or sedentary behaviours assessed in ORI compared to OSI. This is surprising considering the obesity-promoting features of an obesogenic environment are increased energy intake coupled with decreased energy expenditure. The most notable dietary intake difference was a significantly lower intake of energy relative to BW in OSI compared to ORI. This finding does not appear to be the result of low energy reporting, but along with a lower RMR relative to BW, is consistent with OSI self-report that they need to consume less to manage their weight. While it appears obesity resistant and obesity susceptible individuals engage in similar levels of PA and sedentary behaviour, a larger sample size may be better able to tease out small differences in overall PA which could have relevance in altering energy expenditure in the longer term.

The results of the randomised, placebo-controlled, double-blind, parallel study indicated ORI and OSI responded similarly to 8 weeks daily consumption of a
sugar-sweetened (SS) beverage by increasing BW, compared to consumption of a low calorie alternative. We hypothesized that ORI would be better at compensating for additional calories, however, this lack of difference may indicate that there are no differences in compensation capabilities between ORI and OSI. An equally plausible explanation is that the results have been influenced by the choice to use a beverage as the delivery vehicle of the additional calories, rather than a solid food. It has been suggested the ability to perceive calories from fluids compared to calories from food differs due to energy-containing beverages eliciting a weaker satiety and compensatory dietary response than solid food [216-218]. These findings add to the growing body of evidence of the negative effects of SS beverages on BW and indicate that both obesity resistant and obesity susceptible individuals are vulnerable to insidious effects of SS beverages on weight control.

5.2 Areas for Future Research
The findings from this research have revealed a number of areas that could be addressed in future studies:

- Similar hormone patterns and appetite responses were observed over a 4 hour period amongst ORI compared to OSI in response to a standardised meal consumed in the morning. It would be of interest to investigate the responses of both groups to an ad libitum meal following the 4 hour testing procedures. Measurements of interest could include meal size, dietary composition and hunger and satiety responses before and after eating. In addition, as ghrelin concentrations have been shown to vary in cyclic fashion in response to diurnal rhythms and meal taking, it would also be interesting to measure the 24 hour hormone profiles of ORI compared to OSI.

- Three commonly used prediction equations overestimated the RMR of OSI, especially female OSI. Future investigations may explore the development of RMR prediction equations that include calibration for obesity resistance/susceptibility (ORS) category. Such equations would valuable in providing appropriate energy intake targets for weight loss for OSI.
• Dietary intake measured using a four-day weighed diet record (4DDR) was very similar amongst ORI compared to OSI. This method of dietary assessment provides a ‘snapshot’ of dietary intake. Future studies could incorporate multiple diet records in order to investigate broader dietary habits. Inclusion of a larger sample size could also enable comparison of dietary patterns and diet quality between the two study groups.

• A larger sample size should be used in future studies investigating physical activity and sedentary behaviour amongst ORI and OSI to provide greater statistical power to detect small, but important differences in overall PA. Both subjective and objective measures should be included in future investigations in order to capture multiple aspects of PA and sedentary behaviour.

• A number of differences were found in a variety of eating behaviour constructs amongst ORI and OSI. Eating behaviour is a characteristic that appears to have the potential to be modified. Therefore, it would be of interest to examine eating behaviour modification/retraining amongst OSI using a randomised, controlled study design. Results from this type of study may in turn provide support for the inclusion of eating behaviour modification/retraining in weight management programmes.

• In the present study, although external eating was not associated with ORS category, this was only assessed at the individual level by the Dutch Eating Behaviour Questionnaire (DEBQ). Future investigations could include an examination of social and environmental factors that may influence the eating behaviour of ORI and OSI.

• Obesity resistant individuals (ORI) displayed higher sensitivity to oral fatty acid ingestion compared to OSI, but there was no evidence that ORI were better at ranking fat levels in a custard sample. To clarify if differences exist in the ability of ORI and OSI to detect differences in fat levels, future studies could aim to assess fat ranking ability using a variety of different foods. In addition, it appears sensitivity to fat can be recalibrated. Future research could also investigate the effects of changing fat sensitivity amongst OSI and if these changes persist in the long term.
One of the potential reasons why no differences were observed in the compensation capabilities of ORI compared to OSI may have been because a beverage rather than solid food was used to deliver the additional calories. It would be of interest to replicate the randomised, placebo-controlled, double-blind, parallel design of the IceT study but using an energy-containing solid food and a lower energy equivalent as the placebo.

It is more than likely there are other, as yet, unidentified or unstudied characteristics of obesity resistant individuals that assist this group in maintaining a healthy BW in an obesogenic environment. Future studies aiming to investigate these characteristics should continue to work on developing a system to classify obesity resistant and obesity susceptible individuals that combines elements of self-identification, personal/family weight history and BMI.
References


Appendices
**Appendix A.** Email Granting Permission to Reproduce Fig. 2.1. Possible changes over time in the population distribution of body mass index (BMI).

From: Alan Penman [apenman@umc.edu]
Sent: Thursday, 17 September 2015 12:32 a.m.
To: Rebecca Cooke
Subject: Re: Permission request to reprint a figure

Rebecca: you are more than welcome to use that figure. Good luck with the thesis.

Best,
Alan Penman.

Sent from my iPad

> On Sep 15, 2015, at 6:06 PM, Rebecca Cooke <rebecca.cooke@otago.ac.nz> wrote:
> 
> Dear Professor Penman,
> My name is Rebecca Cooke and I am currently completing my PhD in the Department of Human Nutrition at Otago University in Dunedin, New Zealand. The title of my thesis is: Characteristics of obesity resistance and susceptibility. I am writing to ask permission to adapt and use a figure from one of your publications:
> 
> Penman AD, Johnson WD. The changing shape of the body mass index distribution curve in the population: implications for public health policy to reduce the prevalence of adult obesity. Preventing Chronic Disease, 2006 Jul. Available from: URL: [https://urldefense.proofpoint.com/v2/url?u=http-3A__www.cdc.gov_pcd_issues_2006_jul_05-5F0232.htm&d=BQIFAg&c=lsRuZCB16GuC9L6xVrEM6HFPHFkrIPlkLkYs_JBYHk&r=a24zP0jqCrFDFZj58lfRkg&m=pNz_qvNWEhDTfNYQakfIU_NjbyExd-fiWO7SG0D16jQs&s=o0tunRSFEYLaj0oY3i8GLSTqtzzrW1T6kVMbhJc9Y0&e=](https://urldefense.proofpoint.com/v2/url?u=http-3A__www.cdc.gov_pcd_issues_2006_jul_05-5F0232.htm&d=BQIFAg&c=lsRuZCB16GuC9L6xVrEM6HFPHFkrIPlkLkYs_JBYHk&r=a24zP0jqCrFDFZj58lfRkg&m=pNz_qvNWEhDTfNYQakfIU_NjbyExd-fiWO7SG0D16jQs&s=o0tunRSFEYLaj0oY3i8GLSTqtzzrW1T6kVMbhJc9Y0&e=)
> 
> Figure 1: Possible changes over time in the population distribution of body mass index (see attached)
> 
> I would like to use the figure to help illustrate that population distribution of BMI is positively skewed and that despite exposure to the obesogenic environment, there remains a significant number of people who appear resistant to obesity.
> 
> Could you please let me know if you will grant permission for the use of this figure within my thesis.
> 
> Regards
> Rebecca Cooke
> 
> Department of Human Nutrition
> University of Otago
> PO Box 56
> Dunedin
> New Zealand
> +64 3 479 7518
Appendix B. B2BL Study Participant Recruitment Advertisements

Advertisement for obesity resistant individuals (ORI)

Born to be Lean?

Can you eat whatever you like and not gain weight?

Is putting on weight difficult for you?

The Department of Human Nutrition is looking for volunteers to participate in a study to see why some people maintain their weight with relative ease while others struggle.

You will be required to attend 4 clinic appointments.

You will be remunerated for your time.

This study has been approved by the Human Ethics Committee of the University of Otago.

If you are a non-smoker aged 20-45 years and would like further information please contact:

Sara Macdonald
Tel 479 5430
Email sara.macdonald@otago.ac.nz
Department of Human Nutrition

Born to be Lean?

No matter how little you eat, is maintaining your body weight difficult?

Does it seem like you only have to look at food to gain weight?

The Department of Human Nutrition is looking for volunteers to participate in a study to see why some people maintain their weight with relative ease while others struggle.

You will be required to attend 4 clinic appointments.

You will be remunerated for your time.

This study has been approved by the Human Ethics Committee of the University of Otago.

If you are a non-smoker aged 20-45 years and would like further information please contact:

Sara Macdonald
Tel 479 5430
Email sara.macdonald@otago.ac.nz
Appendix C. Weight History Questions from the B2BL Study Questionnaire

Born to be Lean (B2BL) Study
Weight History Questionnaire

1. a. How old were you when you first thought about your body shape or image?
   - □ 5-10 years
   - □ 11-15 years
   - □ 16-20 years
   - □ 21-25 years
   - □ 26-30 years
   - □ >30 years
   - □ I have never thought about body shape/image (go to question 2)

   b. What triggered you to think about body shape/image?

   ______________________________________________________________________________________
   ______________________________________________________________________________________
   ______________________________________________________________________________________
   ______________________________________________________________________________________

For all questions regarding weight and height, please indicate what unit of measure was used (e.g. kilograms, pounds, stones, centimetres, metres, inches, feet)

2. What is your current estimated weight? ______________

3. What is your current estimated height? ______________

4. What was your lightest and heaviest ADULT WEIGHT (≥18 years) that you can remember (non-pregnant)?
   Lightest_________ □ Not Sure
   Heaviest _________ □ Not Sure

5. What was your lightest and heaviest WEIGHT in the previous 12 months (non-pregnant)?
   Lightest_________ □ Not Sure
   Heaviest _________ □ Not Sure
6. Are there any significant events in your life where you can remember your body weight? e.g. 21st Birthday, wedding, rep team selection, research studies etc.

<table>
<thead>
<tr>
<th>Event</th>
<th>Year</th>
<th>Age</th>
<th>Weight</th>
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7. Do you have access to your Plunket book? *(if No go to question 9)*
   - □ Yes
   - □ No

8. What was your birth weight? (please indicate the unit of measure eg pounds, ounces, kilograms)
   - __________
   - □ Don’t know

9. Have you ever changed your eating habits to lose weight?
   - □ Yes
   - □ No *(if No go to question 13)*

   If Yes, please fill in the table below indicating how many times you have changed your eating habits to lose weight, method of dietary change, the weight you lost, and why you wanted to lose weight.

<table>
<thead>
<tr>
<th>Year and duration</th>
<th>Method of dietary change (e.g. Weight Watchers, a dietitian's eating plan, Atkins diet)</th>
<th>Age (in years)</th>
<th>Weight lost</th>
<th>Why did you want to lose weight?</th>
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</thead>
<tbody>
<tr>
<td>Example: 1970 for 6 months</td>
<td>Weight watchers</td>
<td>21</td>
<td>5kg</td>
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</table>
10. What is the greatest amount of weight you have **LOST** in any one period of time?

_________ over _________ months

11. Was some/all of the weight **GAINED BACK** after this period?

☐ Yes
☐ No

If YES, how much weight did you regain? ____ ____  ☐ Don't know

12. Have you used any supplements pills or diet products for **LOSE** weight in the past? (i.e. Complan, protein shakes, bars)

☐ Yes
☐ No

If Yes, what were they?
_______________________________________________________________________________________
_______________________________________________________________________________________
_______________________________________________________________________________________
_______________________________________________________________________________________
_______________________________________________________________________________________
_______________________________________________________________________________________

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13. Throughout your life have you changed your eating habits to gain weight or prevent weight loss?

☐ Yes

☐ No  *(If No you have now completed this section of the questionnaire)*

If Yes please fill in the table below indicating how many times have you tried to gain weight, method of dietary change, the amount of weight gained, and why you wanted to gain weight?

<table>
<thead>
<tr>
<th>Year and duration</th>
<th>Method of dietary change (e.g. a dietitian’s eating plan, bulking diet)</th>
<th>Age (in years)</th>
<th>Weight gained</th>
<th>Why did you want to gain weight?</th>
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</thead>
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<tr>
<td>Example: 2000 for 6 months</td>
<td>Protein Power</td>
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<td>1</td>
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</table>

14. What is the greatest amount of weight **GAINED** in any one period of time?

__________ over __________ months

15. Was the weight **LOST** again after this period?

☐ Yes

☐ No
If **Yes**, how much weight did you lose? ________

16. Have you used any supplement pills or diet products for **GAINING** weight in the past? (i.e. Complan, protein shakes, bars)
   - Yes
   - No

   If **Yes** what were they?
   ___________________________________________________________________________________
   ___________________________________________________________________________________
   ___________________________________________________________________________________
   ___________________________________________________________________________________
   ___________________________________________________________________________________

*Thank you for completing this section of the questionnaire*
Appendix D. B2BL Study Ethical Approval

Dr Rachel Brown
Department of Human Nutrition
Science II Building
University of Otago

8 February 2008
08/005

Dear Dr Brown

Re: Born to be lean

Thank you for your letter to me in response to the concerns of the University of Otago Human Ethics Committee. You have notified the Committee that questions 48a and 48b have been removed from the questionnaire, which hormones are to be tested, and that a statement regarding the ultimate fate of the blood sample has been added to the consent form.

Your proposal continues to be fully approved by the Human Ethics Committee. If the nature, consent, location, procedures or personnel of your approved application change, please advise me in writing. I hope all goes well for you with your upcoming research.

Yours sincerely

Gary Witte
Manager, Academic Committees
University of Otago

cc. Professor Murray Skeaff (Head of Department), Human Nutrition
Thank you for showing an interest in this project. Please read this information sheet carefully before deciding whether or not to participate. If you decide to participate we thank you. If you decide not to take part there will be no disadvantage to you of any kind and we thank you for considering our request.

What is the Aim of the Project?
The aim of this research is to compare biological and lifestyle characteristics of individuals who maintain a healthy body weight with relative ease with those who struggle to maintain a healthy body weight.

What Type of Participants are being sought?
We are seeking males and females aged between 20-45 years who either struggle to maintain a healthy body weight or maintain a healthy body weight with ease (and may even struggle to gain weight).

People who are in one or more of the categories listed below will not be able to participate in the project:

- People with chronic disease such as cancer, heart disease, or diabetes
- People with a medical condition that may affect their metabolic rate
- Smokers
- Post-menopausal females

What will Participants be Asked to Do?
Should you agree to take part in this project, you will be asked to complete a screening questionnaire. If you are eligible for the study you will be asked to attend 3 or 4 clinic visits:

1. At your first clinic visit we will take a blood sample to measure thyroid hormone levels and record your height, weight, and waist and hip circumference. During this visit you will also be given instructions on how to collect a 4-day diet record. This food record will be completed over 3 week days and 1 weekend day.
1. week after you have completed this record we will call you on three separate occasions to perform a 24-hr recall. This is where we will ask you what you have eaten during the previous 24 hours. During visit one we will also provide you with 3 questionnaires that you can return to us in an addressed, pre-paid envelop. These questionnaires will ask for information on demographics, weight history, family weight history, menstrual history, attitudes to exercise and food, eating patterns (past & present), physical activity, medical history, and sleep patterns. Visit 1 will take approximately 45 minutes. Each questionnaire should take around 15-30 minutes to complete. Finally, at this clinic visit we will also give you an accelerometer to take home and wear which will measure your activity levels (eg walking, chores, watching TV, exercise work etc). You will be required to wear the accelerometer for 8 days.

2. At visit 2 you will be asked to go to the 9th floor of the Dunedin Public Hospital (DXA scanner suite) to have a DXA scan. We will ask you to lie on a bed for four scans to be taken with a special DXA scanner, which measures your body fat and muscle. This will take 40 minutes and involves a very small dose of radiation (2uSv), which is less than 1/10th of the radiation received in a single normal chest X-ray. In comparison people living in New Zealand each receive about 2000uSv over a year from natural background radiation.

3. At visit 3 we will measure your resting metabolic rate (RMR) at the School of Physical Education. This is the amount of energy that you need to cover your energy requirements when you are resting. Resting metabolic rate will be measured in the morning after an overnight fast of at least 12 hours. After a 15-minute rest period, expired gas will be collected through a mouthpiece with the nose clipped for a 15-minute period. You will be asked to consume your normal diet and refrain from exercise in the 24-hour period prior to the test. Caffeine or nicotine should also be avoided within 12 hours of the test. Water may be consumed as needed. This appointment will take approximately 45 minutes.

4. You will also be invited to take part in a fourth clinic visit where you will consume a standardised meal. Blood tests will be taken via a fingerprick blood sample before you consume the meal, and at 15, 30, 60, 120 and 180 minutes after consumption of the test meal. After the final blood test you will be invited to eat lunch. The concentration of hormones which are involved in appetite control will be measured in each blood sample. The hormones are called ghrelin, leptin, insulin, peptide YY and glucagons-like protein (GLP). During this test you will also rate your appetite sensations for desire to eat, hunger, fullness and prospective food consumption on a 100mm visual analogue scale. This appointment will take approximately 3 and half hours.

Potential Discomfort
One may experience slight discomfort from the fingerprick blood test. Further, there may be some slight bruising. If bruising does occur, it will disappear within one day. On rare occasions some individuals may feel unwell during or after testing. We have a bed for these individuals to rest on and our research nurse will monitor the situation. If you feel unwell during or after testing you will be provided with a ride home.
Can Participants Change their Mind and Withdraw from the Project?
You may withdraw from participation in the project at any time and without any drawback to yourself of any kind.

What Data or Information will be Collected and What Use will be Made of it?
We will be collecting personal information regarding your sex, age, weight and height, body composition, and lifestyle characteristics. The purpose of collecting this information is so that we are able to describe the overall characteristics of the population and to compare the characteristics of those who find it difficult to maintain a healthy body weight with those who maintain a healthy weight with ease. Only Rachel Brown, Alex Chisholm and Sara Macdonald will have access to personal information and even then only ID numbers will identify individuals. Participants will be given their personal results along with a brief written interpretation of these at the end of the study. The results of this project may be published. Any data will in no way be linked to any specific participant.

The data collected will be securely stored in such a way that only those mentioned above will be able to gain access to it. At the end of the project any personal information will be destroyed immediately except that, as required by the University's research policy, any raw data on which the results of the project depend will be retained in secure storage for five years, after which it will be destroyed.

Reasonable precautions will be taken to protect and destroy data gathered by email. However, the security of electronically transmitted information cannot be guaranteed. Caution is advised in the electronic transmission of sensitive material.

What if Participants have any Questions?
If you have any questions about our project, either now or in the future, please feel free to contact either:

Sara Macdonald or Dr Rachel Brown
Department of Human Nutrition Department of Human Nutrition

University Telephone Number:- 479 5430 University Telephone Number:-479 5839

This project has been reviewed and approved by the University of Otago Human Ethics Committee
Appendix F. B2BL Study Consent form for Participants

Born to be Lean?
CONSENT FORM FOR PARTICIPANTS

I have read the Information Sheet concerning this project and understand what it is about. All my questions have been answered to my satisfaction. I understand that I am free to request further information at any stage.

I know that:-

1. My participation in the project is entirely voluntary;

2. I am free to withdraw from the project at any time without any disadvantage;

3. Personal identifying information will be destroyed at the conclusion of the project but any raw data on which the results of the project depend will be retained in secure storage for five years, after which they will be destroyed;

4. I may experience slight discomfort during the blood test, and some bruising may occur

5. I will receive $5 for each clinic visit to cover my travel costs. If I take part in the 4-hour blood testing procedure I will be reimbursed $50 for my time.

6. The results of the project may be published and will be available in the library but every attempt will be made to preserve my anonymity.

7. Blood samples will not be retained after the project is completed.

8. I understand that reasonable precautions have been taken to protect data transmitted by email but that the security of the information cannot be guaranteed.

I agree to take part in this project.

................................................................................................................. ........................................
(Signature of participant) (Date)

This project has been reviewed and approved by the University of Otago Human Ethics Committee
The Born to be Lean Study

4-Day Diet Record

Department of Human Nutrition
University of Otago
Instructions

Please record in this booklet everything you eat and drink on the following days:

1. Writing down everything you eat and drink can be very inconvenient but try not to change what you consume because you are keeping a record. We can best help you if you give us an honest snapshot of your diet.

2. Please also record the number of people who were present for each eating occasion

Describing foods
The more details you are able to give us about the food and drink you have consumed, the better we are able to estimate your nutrient intake.

You need to describe 3 things:
1. When you eat
2. What you eat
3. How much you eat

WHEN YOU EAT
Simply record the time you eat or drink in the appropriate column

WHAT YOU EAT
Brand names
• Please record the brand name of each food, drink or cooking ingredient where possible. If it is convenient staple the wrapper to this diet record booklet.

Cooking method
• Please describe each item, including cooking details and additions such as salt, sugar, spices and sauces you may have added before cooking

  e.g. egg fried with 1t/p of canola oil
  e.g. Chicken breast with skin on baked in the oven

HOW MUCH YOU EAT
Describing amounts can be difficult. Here are some different options for you to estimate the amount of each food or drink you consume
Electronic Scales
These are probably the best way to record weights. It can take a bit of time but the accuracy is a lot better than some of the other methods. Many people actually prefer to use scales as it is often easy just to put food components onto the scales and then onto your plate.

Household measures
Use cups, glasses, spoons etc.

  e.g. 2 rounded teaspoons of white sugar
  e.g. 1 level tablespoon of margarine

Weights marked on packages

  e.g. 150g Fresh n Fruity yoghurt

Photos of different serving sizes of some popular food and drink items
You will be provided with a booklet which contains photos of different serving sizes of some popular food and drink items. These can often be useful when you go out for a meal and you prefer not to take your scales with you!

  e.g. Barkers strawberry jam, spread B
  e.g. Bran muffin, size C
  e.g. Watties peas, serving size A

Mixed food dishes
For mixed food dishes it may be easier to list the total ingredients, then describe the proportion of this recipe you consumed

  e.g. 1 third of recipe 1

Creamy chicken pasta- Recipe 1

  200g Diamond penne pasta (cooked weight)
  50g mushrooms
  200g grilled chicken breast
  2 teaspoons olive oil
  1 cup carnation evaporated skim milk
  40 g grated cheese
Sample
Please record all food and drink consumed during the each eating occasion on a separate sheet. Include snacks and water.
Remember to report any additions to each food or drink such as milk, sugar, salt, sauce, or spreads
Remember to describe all cooking and preparation methods

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<tr>
<th>Food or Drink</th>
<th>Brand and Details</th>
<th>Preparation/Cooking</th>
<th>Quantity</th>
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</thead>
<tbody>
<tr>
<td>Toast slice bread</td>
<td>Molenburg multigrain</td>
<td>Toasted</td>
<td>2 slices - 74g</td>
</tr>
<tr>
<td>Butter</td>
<td>Anchor</td>
<td></td>
<td>2 tsp</td>
</tr>
<tr>
<td>Strawberry Jam</td>
<td>Pams</td>
<td></td>
<td>Spread B</td>
</tr>
<tr>
<td>Instant Coffee</td>
<td>Nescafe</td>
<td></td>
<td>1 tsp</td>
</tr>
<tr>
<td>Water</td>
<td></td>
<td></td>
<td>200mLs</td>
</tr>
<tr>
<td>Trim milk</td>
<td>Anchor</td>
<td></td>
<td>30mLs</td>
</tr>
<tr>
<td>Sugar</td>
<td></td>
<td></td>
<td>1 teaspoon</td>
</tr>
</tbody>
</table>

How many people did you eat this meal with? __________3_____________

Time meal was started  7.45am
Time meal was finished  8.05am
Day 1- Eating Occasion 1
Please record all food and drink consumed during the each eating occasion on a separate sheet. Include snacks and water.
Remember to report any additions to each food or drink such as milk, sugar, salt, sauce, or spreads
Remember to describe all cooking and preparation methods

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How many people did you eat this meal with? _______________________

Time meal was started  _________________

Time meal was finished  _________________
Day 1- Eating Occasion 2
Please record all food and drink consumed during the each eating occasion on a separate sheet. Include snacks and water. Remember to report any additions to each food or drink such as milk, sugar, salt, sauce, or spreads. Remember to describe all cooking and preparation methods.

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How many people did you eat this meal with? _______________________
Time meal was started  __________________
Time meal was finished  __________________
Day 1- Eating Occasion 3
Please record all food and drink consumed during the each eating occasion on a separate sheet. Include snacks and water. Remember to report any additions to each food or drink such as milk, sugar, salt, sauce, or spreads. Remember to describe all cooking and preparation methods.

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How many people did you eat this meal with? _______________________

Time meal was started  _________________

Time meal was finished  _________________
Day 1- Eating Occasion 4
Please record all food and drink consumed during the each eating occasion on a separate sheet. Include snacks and water. Remember to report any additions to each food or drink such as milk, sugar, salt, sauce, or spreads. Remember to describe all cooking and preparation methods.

<table>
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<th>Food or Drink</th>
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How many people did you eat this meal with? _______________________

Time meal was started  __________________

Time meal was finished  __________________
**Day 1- Eating Occasion 5**

Please record all food and drink consumed during each eating occasion on a separate sheet. Include snacks and water.

Remember to report any additions to each food or drink such as milk, sugar, salt, sauce, or spreads.

Remember to describe all cooking and preparation methods.

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<th>Food or Drink</th>
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How many people did you eat this meal with? _______________________

Time meal was started  __________________

Time meal was finished  __________________
**Day 1- Eating Occasion 6**

Please record all food and drink consumed during the each eating occasion on a separate sheet. Include snacks and water. Remember to report any additions to each food or drink such as milk, sugar, salt, sauce, or spreads.

Remember to describe all cooking and preparation methods.

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How many people did you eat this meal with? _______________________

Time meal was started  __________________

Time meal was finished  ________________
Day 1- Eating Occasion 7
Please record all food and drink consumed during the each eating occasion on a separate sheet. Include snacks and water.
Remember to report any additions to each food or drink such as milk, sugar, salt, sauce, or spreads
Remember to describe all cooking and preparation methods

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How many people did you eat this meal with? ____________________

Time meal was started  _______________

Time meal was finished  _______________
Appendix H. Food Photographs and Weights of Different Portion Sizes
# Food Photo Amounts

**Peas** – Watties Garden peas of McCains broccoli  
<p>| | | | | |</p>
<table>
<thead>
<tr>
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<tbody>
<tr>
<td>A</td>
<td>37g – 60ml (80ml)</td>
<td>B</td>
<td>63g – 100ml (140ml)</td>
<td>C</td>
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</tbody>
</table>

**Vegetable combo** – Watties Chinese Mix  
<p>| | | | | |</p>
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<tbody>
<tr>
<td>A</td>
<td>72g – 130ml</td>
<td>B</td>
<td>127g – 210ml</td>
<td>C</td>
</tr>
</tbody>
</table>

**Rice** – Pams long grain  
<p>| | | | | |</p>
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<tbody>
<tr>
<td>A</td>
<td>108g – 190ml</td>
<td>B</td>
<td>144g – 250ml</td>
<td>C</td>
</tr>
</tbody>
</table>

**Spaghetti** – Diamond, blue pack  
<p>| | | | | |</p>
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</thead>
<tbody>
<tr>
<td>A</td>
<td>100g – 200ml</td>
<td>B</td>
<td>145g – 280ml</td>
<td>C</td>
</tr>
</tbody>
</table>

**Chicken**  
<p>| | | | | |</p>
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<thead>
<tr>
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</thead>
<tbody>
<tr>
<td>A</td>
<td>drumstick, cooked with skin</td>
<td>58g</td>
<td>B</td>
<td>boneless breast, cooked with skin</td>
</tr>
<tr>
<td></td>
<td>without skin</td>
<td>49g</td>
<td></td>
<td>without skin</td>
</tr>
<tr>
<td>B</td>
<td>boneless breast, cooked with skin</td>
<td>192g</td>
<td></td>
<td>breast on bone, cooked with skin</td>
</tr>
<tr>
<td></td>
<td>without skin</td>
<td>176g</td>
<td></td>
<td>without skin</td>
</tr>
</tbody>
</table>

**Stew** – Ernest Adams SuperSnack Beef Casserole  
<p>| | | | | |</p>
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</thead>
<tbody>
<tr>
<td>A</td>
<td>162g – 160ml</td>
<td>B</td>
<td>256g – 250ml</td>
<td>C</td>
</tr>
</tbody>
</table>

**Meat**  
<p>| | | | | |</p>
<table>
<thead>
<tr>
<th></th>
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</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>36g meat + 31g gravy – 60ml</td>
<td>B</td>
<td>72g meat + 63g gravy – 125ml</td>
<td>C</td>
</tr>
</tbody>
</table>

**Hot Chips**  
<p>| | | | | |</p>
<table>
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<tr>
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<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>75g</td>
<td>B</td>
<td>150g</td>
<td>C</td>
</tr>
</tbody>
</table>
Containers

Coffee  215ml
Drink can  355ml
Coke cups  390ml, 610ml, 715ml
Milkshake  710ml
Black  base 230ml
White  base 315ml, lid 315ml, total 630ml
Cream  base 850ml, lid 100ml, total 950ml
Clear  base 1000ml, lid 550ml, total 1550ml

Muffins

A  New World Supermarket  62g
B  Muffin Time  160g
C  Muffin Time  185g

Chocolate

Family block  350g, row 33.6g, piece 4.2g
King block  250g, row 25.2g, piece 4.2g
Nestle block  200g, row 23.5g, piece 4.7g
Large block  150g, row 18.9g, piece 4.7g
Hershey block  40g, row 9.6g, piece 3.2g
Chunky bar  50g, piece 7.1g

Volume of spoons

<table>
<thead>
<tr>
<th></th>
<th>Flat</th>
<th>Rounded</th>
<th>Heaped</th>
</tr>
</thead>
<tbody>
<tr>
<td>Teaspoon</td>
<td>4ml</td>
<td>6ml</td>
<td>14ml</td>
</tr>
<tr>
<td>Dessert spoon</td>
<td>7ml</td>
<td>16ml</td>
<td>20ml</td>
</tr>
<tr>
<td>Tablespoon</td>
<td>14ml</td>
<td>30ml</td>
<td>60ml</td>
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</tbody>
</table>

Peanut butter  Jam/marmalade/honey

<table>
<thead>
<tr>
<th></th>
<th>4g</th>
<th>13g</th>
<th>23g</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>3g</td>
<td></td>
<td></td>
</tr>
<tr>
<td>B</td>
<td>6g</td>
<td></td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>10g</td>
<td></td>
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</tbody>
</table>

Margarine/butter  Vegemite/marmite

<table>
<thead>
<tr>
<th></th>
<th>2g</th>
<th>3.5g</th>
<th>6g</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>3.5g</td>
<td></td>
<td></td>
</tr>
<tr>
<td>B</td>
<td>6g</td>
<td></td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>9.9g</td>
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Cornflakes – Skippy

<table>
<thead>
<tr>
<th></th>
<th>– 280ml</th>
<th>– 430ml</th>
<th>– 560ml</th>
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<tbody>
<tr>
<td>A</td>
<td>30g</td>
<td></td>
<td></td>
</tr>
<tr>
<td>B</td>
<td>45g</td>
<td></td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>60g</td>
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</table>

Muesli – Budget tropical fruit breakfast cereal

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<tr>
<th></th>
<th>– 100ml</th>
<th>– 155ml</th>
<th>– 200ml</th>
</tr>
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<tbody>
<tr>
<td>A</td>
<td>50g</td>
<td></td>
<td></td>
</tr>
<tr>
<td>B</td>
<td>75g</td>
<td></td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>100</td>
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Volume of a sphere = 4/3πr³  Area of a circle = πr²
Appendix I. B2BL Study Accelerometer Instructions

ACCELEROMETER

As part of the BORN TO BE LEAN? study, we want to collect data on the amount of activity you undertake over 7 days. The activity we are interested in isn’t just sports, exercise, or games, but ANY activity (walking, chores, watching TV) that you participate in. As with all data being collected as part of the BORN TO BE LEAN? study, data from individuals will not be identified. We are collecting this data using accelerometers to look at the activity level of the entire group.

Using your accelerometer

The accelerometer MUST be worn around the waist. If it isn’t worn correctly, then it will not able to measure activity levels properly.

The accelerometer can be worn against the skin OR over a singlet or light top which ever is preferred. The band should be fitting, but still comfortable, and the accelerometer should be worn above the hip bone, at waist level.

Ensure that he accelerometer is worn with the arrow pointing UP. (See picture below)

The accelerometer is waterproof, and can withstand swimming, being in the rain, the shower or bath etc. However, the damp belt may be uncomfortable to wear for a short time after becoming wet. If prefer taking it off when showering, please make a note of this on the back of this sheet.

Changing the accelerometer to a new belt

As we want to collect ALL physical activity data, if you do go swimming we would still like you to wear the belt. The change the accelerometer over to a new belt, lift up the Velcro tabs on either side of the accelerometer and gently pull the device away from the belt.

When putting the accelerometer on to the dry belt, ensure that it is put on the belt with the ARROW pointing UP and the belt buckle to the right, as shown on the above diagram.

At night, please take your accelerometer and belt off. As the activity sensor in the accelerometer is very sensitive, please make sure it is placed on a soft, vibration-free surface and left undisturbed. For example, a chair or cushion in a quiet room.
INTERNATIONAL PHYSICAL ACTIVITY QUESTIONNAIRE

We are interested in finding out about the kinds of physical activities that people do as part of their everyday lives.

The questions are about the time you spent being physically active in the last 7 days. They include questions about activities you do at work, as part of your house and garden work, to get from place to place, and in your spare time for recreation, exercise or sport.

Your answers are important.

Please answer each question even if you do not consider yourself to be an active person.

THANK YOU FOR PARTICIPATING.

In answering the following questions,
• **vigorous** physical activities refer to activities that take hard physical effort and make you breathe much harder than normal.
• **moderate** activities refer to activities that take moderate physical effort and make you breathe somewhat harder than normal.
PART 1: JOB-RELATED PHYSICAL ACTIVITY
The first section is about your work. This includes paid jobs, farming, volunteer work, course work and any other unpaid work that you did outside your home. Do not include unpaid work you might do around your home, like housework, yard work, general maintenance, and caring for your family. These are asked in Part 3.

1a. Do you currently have a job or do any unpaid work outside your home?
☐ Yes
☐ No [If No, go to PART 2: TRANSPORTATION]

The next questions are about all the physical activity you did in the last 7 days as part of your paid or unpaid work. This does not include traveling to and from work.

1b. During the last 7 days, on how many days did you do vigorous physical activities like heavy lifting, digging, heavy construction, or climbing up stairs as part of your work? Think about only those physical activities that you did for at least 10 minutes at a time.

   _______ days per week  ➔  1c. How much time in total did you usually spend on one of those days doing vigorous physical activities as part of your work?

   _______ hours _________ minutes

or

☐ none
[If none, go to question 1d]

1d. Again, think about only those physical activities that you did for at least 10 minutes at a time. During the last 7 days, on how many days did you do moderate physical activities like carrying light loads as part of your work? Please do not include walking.

   _______ days per week  ➔  1e. How much time in total did you usually spend on one of those days doing moderate physical activities as part of your work?

   _______ hours _________ minutes

or

☐ none
[If none, go to question 1f]

1f. During the last 7 days, on how many days did you walk for at least 10 minutes at a time as part of your work? Please do not count any walking you did to travel to or from work.

   _______ days per week  ➔  1f. How much time in total did you usually spend on one of those days walking as part of your work?

   _______ hours _________ minutes

or

☐ none
[If none, go to PART 2: TRANSPORTATION]
PART 2: TRANSPORTATION PHYSICAL ACTIVITY

These questions are about how you traveled from place to place, including to places like work, stores, movies and so on.

2a. During the last 7 days, on how many days did you travel in a motor vehicle like a train, bus car or tram?


2b. How much time in total did you usually spend on one of those days traveling in a car, bus, train or other kind of motor vehicle?


or

☐ none

[If none, go to question 2c]

Now think only about the bicycling and walking you might have done to travel to and from work, to do errands, or to go from place to place.

2c. During the last 7 days, on how many days did you bicycle for at least 10 minutes at a time to go from place to place?


2d. How much time in total did you usually spend on one of those days to bicycle from place to place?


or

☐ none

[If none, go to question 2e]

2e. During the last 7 days, on how many days did you walk for at least 10 minutes at a time to go from place to place?


2f. How much time in total did you usually spend on one of those days walking from place to place?


or

☐ none

[If none, go to PART 3: HOUSEWORK, HOUSE MAINTENANCE AND CARING FOR FAMILY]
PART 3. HOUSEWORK, HOUSE MAINTENANCE, AND CARING FOR FAMILY
This section is about some of the physical activities you might have done in the last 7 days *in and around your home*, like housework, gardening, yard work (work around your section), general maintenance work, and caring for your family.

3a. Think about only those physical activities that you did for at least 10 minutes at a time. During the last 7 days, on how many days did you do vigorous physical activities like heavy lifting, chopping wood, shoveling snow, or digging in the garden or yard (section)?

________ days per week ➔ 3b. How much time in total did you usually spend on one of those days doing vigorous physical activities in the garden or yard (section)?

_____ hours _____ minutes

or

☐ none
[If none, go to question 3c]

3c. Again, think about only those physical activities that you did for at least 10 minutes at a time. During the last 7 days, on how many days did you do moderate activities like carrying light loads, sweeping, washing windows, and raking in the garden or yard (section)?

________ days per week ➔ 3d. How much time in total did you usually spend on one of those days doing moderate physical activities in the garden or yard (section)?

_____ hours _____ minutes

or

☐ none
[If none, go to question 3e]

3e. Once again, think about only those physical activities that you did for at least 10 minutes at a time. During the last 7 days, on how many days did you do moderate activities like carrying light loads, washing windows, scrubbing floors and sweeping inside your home?

________ days per week ➔ 3f. How much time in total did you usually spend on one of those days doing moderate physical activities inside your home?

_____ hours _____ minutes

or

☐ none
[If none, go to PART 4: RECREATION, SPORT AND LEISURE-TIME PHYSICAL ACTIVITY]
PART 4: RECREATION, SPORT, AND LEISURE-TIME PHYSICAL ACTIVITY

This section is about all the physical activities that you did in the last 7 days solely for recreation, sport, exercise or leisure. Please do NOT include any activities you have already mentioned.

4a. Not counting any walking you have already mentioned, during the last 7 days, on how many days did you walk for at least 10 minutes at a time in your leisure time?

_________ days per week ➔ 4b. How much time in total did you usually spend on one of those days walking in your leisure time?

______ hours _____ minutes

or

☐ none

[If none, go to question 4c]

4c. Think about only those physical activities that you did for at least 10 minutes at a time. During the last 7 days, on how many days did you do vigorous physical activities like aerobics, running, fast bicycling, or fast swimming in your leisure time?

_________ days per week ➔ 4d. How much time in total did you usually spend on one of those days doing vigorous physical activities in your leisure time?

______ hours _____ minutes

or

☐ none

[If none, go to question 4e]

4e. Again, think about only those physical activities that you did for at least 10 minutes at a time. During the last 7 days, on how many days did you do moderate physical activities like bicycling at a regular pace, swimming at a regular pace, and doubles tennis in your leisure time?

_________ days per week ➔ 4f. How much time in total did you usually spend on one of those days doing moderate physical activities in your leisure time?

______ hours _____ minutes

or

☐ none

[If none, go to PART 5: TIME SPENT SITTING]
PART 5: TIME SPENT SITTING
The last questions are about the time you spend sitting while at work, at home, while doing course work and during leisure time. This may include time spent sitting at a desk, visiting friends, reading or sitting or lying down to watch television. Do not include any time spent sitting in a motor vehicle that you have already told me about.

5a. During the last 7 days, how much time in total did you usually spend sitting on a week day?
_____ hours _____ minutes

5b. During the last 7 days, how much time in total did you usually spend sitting on a weekend day?
_____ hours _____ minutes

This is the end of questionnaire, thank you for participating.
Appendix K. Guidelines for Data Processing and Analysis of the IPAQ

Guidelines for Data Processing and Analysis of the International Physical Activity Questionnaire (IPAQ)

– Short and Long Forms

November 2005

Contents
1. Introduction
2. Uses of IPAQ Instruments
3. Summary Characteristics of Short and Long Forms
4. Overview of Continuous and Categorical Analyses of IPAQ
5. Protocol for Short Form
6. Protocol for Long Form
7. Data Processing Rules
8. Summary Algorithms

Appendix 1. At A Glance IPAQ Scoring Protocol – Short Forms
Appendix 2. At A Glance IPAQ Scoring Protocol – Long Forms
1. Introduction

This document describes recommended methods of scoring the data derived from the telephone / interview administered and self-administered IPAQ short and long form instruments. The methods outlined provide a revision to earlier scoring protocols for the IPAQ short form and provide for the first time a comparable scoring method for IPAQ long form. Latest versions of IPAQ instruments are available from www.ipaq.ki.se.

Although there are many different ways to analyse physical activity data, to date there is no formal consensus on a ‘correct’ method for defining or describing levels of physical activity based on self-report population surveys. The use of different scoring protocols makes it very difficult to compare within and between countries, even when the same instrument has been used. Use of these scoring methods will enhance the comparability between surveys, provided identical sampling and survey methods have been used.

2. Uses of IPAQ Instruments

IPAQ short form is an instrument designed primarily for population surveillance of physical activity among adults. It has been developed and tested for use in adults (age range of 15-89 years) and until further development and testing is undertaken the use of IPAQ with older and younger age groups is not recommended.

IPAQ short and long forms are sometimes being used as an evaluation tool in intervention studies, but this was not the intended purpose of IPAQ. Users should carefully note the range of domains and types of activities included in IPAQ before using it in this context. Use as an outcome measure in small scale intervention studies is not recommended.

3. Summary Characteristics of IPAQ Short and Long Forms

1. IPAQ assesses physical activity undertaken across a comprehensive set of domains including:
   a. leisure time physical activity
   b. domestic and gardening (yard) activities
   c. work-related physical activity
   d. transport-related physical activity;

2. The IPAQ short form asks about three specific types of activity undertaken in the four domains introduced above. The specific types of activity that are assessed are walking, moderate-intensity activities and vigorous-intensity activities.

3. The items in the short IPAQ form were structured to provide separate scores on walking, moderate-intensity and vigorous-intensity activity. Computation of the total score for the short form requires summation of the duration (in minutes) and frequency (days) of walking, moderate-intensity and vigorous-intensity activities. Domain specific estimates cannot be estimated.
4. The IPAQ long form asks details about the specific types of activities undertaken within each of the four domains. Examples include walking for transportation and moderate-intensity leisure-time activity.

5. The items in the long IPAQ form were structured to provide separate domain specific scores for walking, moderate-intensity and vigorous-intensity activity within each of the work, transportation, domestic chores and gardening (yard) and leisure-time domains. Computation of the total scores for the long form requires summation of the duration (in minutes) and frequency (days) for all the types of activities in all domains. Domain specific scores or activity specific sub-scores may be calculated. Domain specific scores require summation of the scores for walking, moderate-intensity and vigorous-intensity activities within the specific domain, whereas activity-specific scores require summation of the scores for the specific type of activity across domains.

4. Overview of Continuous and Categorical Analyses of IPAQ

Both categorical and continuous indicators of physical activity are possible from both IPAQ forms. However, given the non-normal distribution of energy expenditure in many populations, it is suggested that the continuous indicator be presented as median minutes/week or median MET-minutes/week rather than means (such as mean minutes/week or mean MET-minutes/week).

4.1 Continuous Variables

Data collected with IPAQ can be reported as a continuous measure. One measure of the volume of activity can be computed by weighting each type of activity by its energy requirements defined in METs to yield a score in MET-minutes. METs are multiples of the resting metabolic rate and a MET-minute is computed by multiplying the MET score of an activity by the minutes performed. MET-minute scores are equivalent to kilocalories for a 60 kilogram person. Kilocalories may be computed from MET-minutes using the following equation: MET-min x (weight in kilograms / 60 kilogram). MET-minutes/day or MET-minutes/week can be presented although the latter is more frequently used and is thus suggested.

Details for the computation for summary variables from IPAQ short and long forms are detailed below. As there are no established thresholds for presenting MET-minutes, the IPAQ Research Committee propose that these data are reported as comparisons of median values and interquartile ranges for different populations.

4.2 Categorical Variable: Rationale for Cut Point Values

There are three levels of physical activity proposed to classify populations:

1. Low
2. Moderate
3. High
The algorithms for the short and long forms are defined in more detail in Sections 5.3 and 6.3, respectively. Rules for data cleaning and processing prior to computing the algorithms appear in Section 7.

Regular participation is a key concept included in current public health guidelines for physical activity. Therefore, both the total volume and the number of days/session are included in the IPAQ analysis algorithms.

The criteria for these levels have been set taking into account that IPAQ asks questions in all domains of daily life, resulting in higher median MET-minutes estimates than would have been estimated from leisure-time participation alone. The criteria for these three levels are shown below.

Given that measures such as IPAQ assess total physical activity in all domains, the “leisure time physical activity” based public health recommendation of 30 minutes on most days will be achieved by most adults in a population. Although widely accepted as a goal, in absolute terms 30 minutes of moderate-intensity activity is low and broadly equivalent to the background or basal levels of activity adult individuals would accumulate in a day. Therefore a new, higher output is needed to describe the levels of physical activity associated with health benefits for measures such as IPAQ, which report on a broad range of domains of physical activity.

‘High’

This category was developed to describe higher levels of participation. Although it is known that greater health benefits are associated with increased levels of activity there is no consensus on the exact amount of activity for maximal benefit. In the absence of any established criteria, the IPAQ Research Committee proposes a measure which equates to approximately at least one hour per day or more, of at least moderate-intensity activity above the basal level of physical activity. Considering that basal activity may be considered to be equivalent to approximately 5000 steps per day, it is proposed that “high active” category be considered as those who move at least 12,500 steps per day, or the equivalent in moderate and vigorous activities. This represents at least an hour more moderate-intensity activity over and above the basal level of activity, or half an hour of vigorous-intensity activity over and above basal levels daily. These calculations were based on emerging results of pedometer studies.

This category provides a higher threshold of measures of total physical activity and is a useful mechanism to distinguish variation in population groups. Also it could be used to set population targets for health-enhancing physical activity when multi-domain instruments, such as IPAQ are used.

'Moderate'

This category is defined as doing some activity, more than the low active category. It is proposed that it is a level of activity equivalent to "half an hour of at least moderate-intensity PA on most days", the former leisure time-based physical activity population health recommendation.

'Low'

This category is simply defined as not meeting any of the criteria for either of the previous categories.

5. Protocol for IPAQ Short Form

5.1 Continuous Scores

Median values and interquartile ranges can be computed for walking (W), moderate-intensity activities (M), vigorous-intensity activities (V) and a combined total physical activity score. All continuous scores are expressed in MET-minutes/week as defined below.

5.2 MET Values and Formula for Computation of MET-minutes/week

The selected MET values were derived from work undertaken during the IPAQ Reliability Study undertaken in 2000-2001\(^3\). Using the Ainsworth et al. Compendium (Med Sci Sports Med 2000) an average MET score was derived for each type of activity. For example, all types of walking were included and an average MET value for walking was created. The same procedure was undertaken for moderate-intensity activities and vigorous-intensity activities. The following values continue to be used for the analysis of IPAQ data: Walking = 3.3 METs, Moderate PA = 4.0 METs and Vigorous PA = 8.0 METs. Using these values, four continuous scores are defined:

\[
\text{Walking MET-minutes/week} = 3.3 \times \text{walking minutes} \times \text{walking days} \\
\text{Moderate MET-minutes/week} = 4.0 \times \text{moderate-intensity activity minutes} \times \text{moderate days} \\
\text{Vigorous MET-minutes/week} = 8.0 \times \text{vigorous-intensity activity minutes} \times \text{vigorous-intensity days} \\
\text{Total physical activity MET-minutes/week} = \text{sum of Walking + Moderate + Vigorous MET-minutes/week scores.}
\]

5.3 Categorical Score

Category 1 Low

This is the lowest level of physical activity. Those individuals who do not meet criteria for Categories 2 or 3 are considered to have a 'low' physical activity level.

Category 2  Moderate

The pattern of activity to be classified as 'moderate' is either of the following criteria:
   a) 3 or more days of vigorous-intensity activity of at least 20 minutes per day
      OR
   b) 5 or more days of moderate-intensity activity and/or walking of at least 30
      minutes per day
      OR
   c) 5 or more days of any combination of walking, moderate-intensity or vigorous
      intensity activities achieving a minimum Total physical activity of at least 600
      MET-minutes/week.

Individuals meeting at least one of the above criteria would be defined as
accumulating a minimum level of activity and therefore be classified as 'moderate'.
See Section 7.5 for information about combining days across categories.

Category 3  High

A separate category labelled "high" can be computed to describe higher levels of
participation.
The two criteria for classification as 'high' are:
   a) vigorous-intensity activity on at least 3 days achieving a minimum Total
      physical activity of at least 1500 MET-minutes/week
      OR
   b) 7 or more days of any combination of walking, moderate-intensity or
      vigorous-intensity activities achieving a minimum Total physical activity
      of at least 3000 MET-minutes/week.

See Section 7.5 for information about combining days across categories.

5.4  Sitting Question in IPAQ Short Form

The IPAQ sitting question is an additional indicator variable of time spent in
sedentary activity and is not included as part of any summary score of physical
activity. Data on sitting should be reported as median values and interquartile ranges.
To-date there are few data on sedentary (sitting) behaviours and no well-accepted
thresholds for data presented as categorical levels.

6.  Protocol for IPAQ Long Form

The long form of IPAQ asks in detail about walking, moderate-intensity and vigorous-
intensity physical activity in each of the four domains. Note: asking more detailed
questions regarding physical activity within domains is likely to produce higher
prevalence estimates than the more generic IPAQ short form.
6.1 Continuous Score

Data collected with the IPAQ long form can be reported as a continuous measure and reported as median MET-minutes. Median values and interquartile ranges can be computed for walking (W), moderate-intensity activities (M), and vigorous-intensity activities (V) within each domain using the formulas below. Total scores may also be calculated for walking (W), moderate-intensity activities (M), and vigorous-intensity activities (V); for each domain (work, transport, domestic and garden, and leisure) and for an overall grand total.

6.2 MET Values and Formula for Computation of MET-minutes

Work Domain
Walking MET-minutes/week at work = 3.3 * walking minutes * walking days at work
Moderate MET-minutes/week at work = 4.0 * moderate-intensity activity minutes * moderate-intensity days at work
Vigorous MET-minutes/week at work = 8.0 * vigorous-intensity activity minutes * vigorous-intensity days at work
Total Work MET-minutes/week = sum of Walking + Moderate + Vigorous MET-minutes/week scores at work.

Active Transportation Domain
Walking MET-minutes/week for transport = 3.3 * walking minutes * walking days for transportation
Cycle MET-minutes/week for transport = 6.0 * cycling minutes * cycle days for transportation
Total Transport MET-minutes/week = sum of Walking + Cycling MET-minutes/week scores for transportation.

Domestic and Garden [Yard Work] Domain
Vigorous MET-minutes/week yard chores = 5.5 * vigorous-intensity activity minutes * vigorous-intensity days doing yard work (Note: the MET value of 5.5 indicates that vigorous gardening/yard work should be considered a moderate-intensity activity for scoring and computing total moderate intensity activities.)
Moderate MET-minutes/week yard chores = 4.0 * moderate-intensity activity minutes * moderate-intensity days doing yard work
Moderate MET-minutes/week inside chores = 3.0 * moderate-intensity activity minutes * moderate-intensity days doing inside chores.
Total Domestic and Garden MET-minutes/week = sum of Vigorous yard + Moderate yard + Moderate inside chores MET-minutes/week scores.

Leisure-Time Domain
Walking MET-minutes/week leisure = 3.3 * walking minutes * walking days in leisure
Moderate MET-minutes/week leisure = 4.0 * moderate-intensity activity minutes * moderate-intensity days in leisure
Vigorous MET-minutes/week leisure = 8.0 * vigorous-intensity activity minutes * vigorous-intensity days in leisure
Total Leisure-Time MET-minutes/week = sum of Walking + Moderate + Vigorous MET-minutes/week scores in leisure.
Total Scores for all Walking, Moderate and Vigorous Physical Activities

Total Walking MET-minutes/week = Walking MET-minutes/week (at Work + for Transport + in Leisure)
Total Moderate MET-minutes/week total = Moderate MET-minutes/week (at Work + Yard chores + inside chores + in Leisure time) + Cycling MET-minutes/week for Transport + Vigorous Yard chores MET-minutes/week
Total Vigorous MET-minutes/week = Vigorous MET-minutes/week (at Work + in Leisure)

Note: Cycling MET value and Vigorous garden/yard work MET value fall within the coding range of moderate-intensity activities.

Total Physical Activity Scores

An overall total physical activity MET-minutes/week score can be computed as:
Total physical activity MET-minutes/week = sum of Total (Walking + Moderate + Vigorous) MET-minutes/week scores.

This is equivalent to computing:
Total physical activity MET-minutes/week = sum of Total Work + Total Transport + Total Domestic and Garden + Total Leisure-Time MET-minutes/week scores.

As there are no established thresholds for presenting MET-minutes, the IPAQ Research Committee proposes that these data are reported as comparisons of median values and interquartile ranges for different populations.

6.3 Categorical Score

As noted earlier, regular participation is a key concept included in current public health guidelines for physical activity. Therefore, both the total volume and the number of day/sessions are included in the IPAQ analysis algorithms. There are three levels of physical activity proposed to classify populations – ‘low’, ‘moderate’, and ‘high’. The criteria for these levels are the same as for the IPAQ short [described earlier in Section 4.2]

Category 1 Low

This is the lowest level of physical activity. Those individuals who not meet criteria for Categories 2 or 3 are considered ‘low’.

Category 2 Moderate

The pattern of activity to be classified as ‘moderate’ is either of the following criteria:

d) 3 or more days of vigorous-intensity activity of at least 20 minutes per day
OR
e) 5 or more days of moderate-intensity activity and/or walking of at least 30 minutes per day

---

f) 5 or more days of any combination of walking, moderate-intensity or vigorous-intensity activities achieving a minimum Total physical activity of at least 600 MET-minutes/week.

Individuals meeting at least one of the above criteria would be defined as accumulating a moderate level of activity. See Section 7.5 for information about combining days across categories.

**Category 3 High**

A separate category labelled 'high' can be computed to describe higher levels of participation.

The two criteria for classification as 'high' are:

a) vigorous-intensity activity on at least 3 days achieving a minimum Total physical activity of at least 1500 MET-minutes/week

OR

b) 7 or more days of any combination of walking, moderate-intensity or vigorous-intensity activities achieving a minimum Total physical activity of at least 3000 MET-minutes/week.

See Section 7.5 for information about combining days across categories.

### 6.4 IPAQ Sitting Question IPAQ Long Form

The IPAQ sitting question is an additional indicator variable and is not included as part of any summary score of physical activity. To-date there are few data on sedentary (sitting) behaviours and no well-accepted thresholds for data presented as categorical levels. For the sitting question 'Minutees' is used as the indicator to reflect time spent in sitting rather than MET-minutes which would suggest an estimate of energy expenditure.

IPAQ long assesses an estimate of sitting on a typical weekday, weekend day and time spent sitting during travel (see transport domain questions).

**Summary sitting variables include**

Sitting Total Minutes/week = weekday sitting minutes* 5 weekdays + weekend day sitting minutes* 2 weekend days

Average Sitting Total Minutes/weekday = (weekday sitting minutes* 5 weekdays + weekend day sitting minutes* 2 weekend days) / 7

**Note:** The above calculation of 'Sitting Total' excludes time spent sitting during travel because the introduction in IPAQ long directs the responder to NOT include this component as it would have already been captured under the Transport section. If a summary sitting variable including time spent sitting for transport is required, it should be calculated by adding the time reported (travelling in a motor vehicle) under transport to the above formula. Care should be taken in reporting these alternate data to clearly distinguish the 'total sitting' variable from a 'total sitting – including transport' variable.
7. **Data Processing Rules**

In addition to a standardized approach to computing categorical and continuous measures of physical activity, it is necessary to undertake standard methods for the cleaning and treatment of IPAQ datasets. The use of different approaches and rules would introduce variability and reduce the comparability of data.

There are no established rules for data cleaning and processing on physical activity. Thus, to allow more accurate comparisons across studies IPAQ Research Committee has established and recommends the following guidelines:

7.1 **Data Cleaning**

I. Any responses to duration (time) provided in the hours and minutes response option should be converted from hours and minutes into minutes.

II. To ensure that responses in ‘minutes’ were not entered in the ‘hours’ column by mistake during self-completion or during data entry process, values of ‘15’, ‘30’, ‘45’, ‘60’ and ‘90’ in the ‘hours’ column should be converted to ‘15’, ‘30’, ‘45’, ‘60’ and ‘90’ minutes, respectively, in the minutes column.

III. In some cases duration (time) will be reported as weekly (not daily) e.g., VWHRS, VWMINS. These data should be converted into an average daily time by dividing by 7.

IV. If ‘don’t know’ or ‘refused’ or data are missing for time or days then that case is removed from analysis.

**Note:** Both the number of days and daily time are required for the creation of categorical and continuous summary variables

7.2 **Maximum Values for Excluding Outliers**

This rule is to exclude data which are unreasonably high; these data are to be considered outliers and thus are excluded from analysis. All cases in which the sum total of all Walking, Moderate and Vigorous time variables is greater than 960 minutes (16 hours) should be excluded from the analysis. This assumes that an average individual of 8 hours per day is spent sleeping.

The ‘days’ variables can take the range 0-7 days, or 8, 9 (don’t know or refused); values greater than 9 should not be allowed and those cases excluded from analysis.

7.3 **Minimum Values for Duration of Activity**

Only values of 10 or more minutes of activity should be included in the calculation of summary scores. The rationale being that the scientific evidence indicates that episodes or bouts of at least 10 minutes are required to achieve health benefits. Responses of less than 10 minutes [and their associated days] should be re-coded to ‘zero’.
7.4 Truncation of Data Rules

This rule attempts to normalize the distribution of levels of activity which are usually skewed in national or large population data sets.

In IPAQ short - it is recommended that all Walking, Moderate and Vigorous time variables exceeding ‘3 hours’ or ‘180 minutes’ are truncated (that is re-coded) to be equal to ‘180 minutes’ in a new variable. This rule permits a maximum of 21 hours of activity in a week to be reported for each category (3 hours × 7 days).

In IPAQ long – the truncation process is more complicated, but to be consistent with the approach for IPAQ short requires that the variables total Walking, total Moderate-intensity and total Vigorous-intensity activity are calculated and then, for each of these summed behaviours, the total value should be truncated to 3 hours (180 minutes).

When analysing the data as categorical variable or presenting median and interquartile ranges of the MET-minute scores, the application of the truncation rule will not affect the results. This rule does have the important effect of preventing misclassification in the ‘high’ category. For example, an individual who reports walking for 10 minutes on 6 days and 12 hours of moderate activity on one day could be coded as ‘high’ because this pattern meets the ‘7 day’ and ‘3000 MET-min’ criteria for ‘high’. However, this uncommon pattern of activity is unlikely to yield the health benefits that the ‘high’ category is intended to represent.

Although using median is recommended due to the skewed distribution of scores, if IPAQ data are analysed and presented as a continuous variable using mean values, the application of the truncation rule will produce slightly lower mean values than would otherwise be obtained.

7.5 Calculating MET-minute/week Scores

Data processing rules 7.2, 7.3, and 7.4 deals first with excluding outlier data, then secondly, with recoding minimum values and then finally dealing with high values. These rules will ensure that highly active people remain classified as ‘high’, while decreasing the chances that less active individuals are misclassified and coded as ‘high’.

Using the resulting variables, convert time and days to MET-minute/week scores [see above Sections 5.2 and 6.2; METS x days x daily time].

7.6 Calculating Total Days for Presenting Categorical Data on Moderate and High Levels

Presenting IPAQ data using categorical variables requires the total number of ‘days’ on which all physical activity was undertaken to be assessed. This is difficult because frequency in ‘days’ is asked separately for walking, moderate-intensity and vigorous-intensity activities, thus allowing the total number of ‘days’ to range from a minimum
of 0 to a maximum of 21 'days' per week in IPAQ short and higher in IPAQ long. The IPAQ instrument does not record if different types of activity are undertaken on the same day.

In calculating 'moderately active', the primary requirement is to identify those individuals who undertake activity on at least '5 days/week [see Sections 4.2 and 5.3]. Individuals who meet this criterion should be coded in a new variable called "at least five days" and this variable should be used to identify those meeting criterion b) at least 30 minutes of moderate-intensity activity and/or walking; and those meeting criterion c) any combination of walking, moderate-intensity or vigorous-intensity activities achieving a minimum of 600 MET-minutes/week.

Below are two examples showing this coding in practice:

i) an individual who reports '2 days of moderate-intensity' and '3 days of walking' should be coded as a value indicating "at least five days";

ii) an individual reporting '2 days of vigorous-intensity', '2 days of moderate-intensity' and '2 days of walking should be coded as a value to indicate "at least five days" [even though the actual total is 6].

The original frequency of 'days' for each type of activity should remain in the data file for use in the other calculations.

The same approach as described above is used to calculate total days for computing the 'high' category. The primary requirement according to the stated criteria is to identify those individuals who undertake a combination of walking, moderate-intensity and or vigorous-intensity activity on at least 7 days/week [See section 4.2]. Individuals who meet this criterion should be coded as a value in a new variable to reflect "at least 7 days".

Below are two examples showing this coding in practice:

i) an individual who reports '4 days of moderate-intensity' and '3 days of walking' should be coded as the new variable "at least 7 days".

ii) an individual reporting '3 days of vigorous-intensity', '3 days moderate-intensity' and '3 days walking' should be coded as "at least 7 days" [even though the total adds to 9].

8. Summary algorithms

The algorithms in Appendix 1 and Appendix 2 to this document show how these rules work in an analysis plan, to develop the categories 1 [Low], 2 [Moderate], and 3 [High] levels of activity.

IPAQ Research Committee
November 2005
APPENDIX 1

At A Glance
IPAQ Scoring Protocol (Short Forms)

Continuous Score
Expressed as MET-min per week: MET level x minutes of activity/day x days per week

Sample Calculation

<table>
<thead>
<tr>
<th>MET levels</th>
<th>MET-minutes/week for 30 min/day, 5 days</th>
</tr>
</thead>
<tbody>
<tr>
<td>Walking = 3.3 METs</td>
<td>3.3<em>30</em>5 = 495 MET-minutes/week</td>
</tr>
<tr>
<td>Moderate Intensity = 4.0 METs</td>
<td>4.0<em>30</em>5 = 600 MET-minutes/week</td>
</tr>
<tr>
<td>Vigorous Intensity = 8.0 METs</td>
<td>8.0<em>30</em>5 = 1,200 MET-minutes/week</td>
</tr>
<tr>
<td></td>
<td><strong>TOTAL = 2,295 MET-minutes/week</strong></td>
</tr>
</tbody>
</table>

Total MET-minutes/week = Walk (METs*min*days) + Mod (METs*min*days) + Vig (METs*min*days)

Categorical Score- three levels of physical activity are proposed

1. **Low**
   - No activity is reported OR
   - Some activity is reported but not enough to meet Categories 2 or 3.

2. **Moderate**
   Either of the following 3 criteria
   - 3 or more days of vigorous activity of at least 20 minutes per day OR
   - 5 or more days of moderate-intensity activity and/or walking of at least 30 minutes per day OR
   - 5 or more days of any combination of walking, moderate-intensity or vigorous-intensity activities achieving a minimum of at least 600 MET-minutes/week.

3. **High**
   Any one of the following 2 criteria
   - Vigorous-intensity activity on at least 3 days and accumulating at least 1500 MET-minutes/week OR
   - 7 or more days of any combination of walking, moderate- or vigorous-intensity activities accumulating at least 3000 MET-minutes/week

Please review the full document "Guidelines for the data processing and analysis of the International Physical Activity Questionnaire" for more detailed description of IPAQ analysis and recommendations for data cleaning and processing [www.ipaq.ki.se].
APPENDIX 2

At A Glance
IPAQ Scoring Protocol (Long Forms)

Continuous Score

Expressed as MET-minutes per week: MET level x minutes of activity/day x days per week

Sample Calculation

<table>
<thead>
<tr>
<th>MET levels</th>
<th>MET-minutes/week for 30 min/day, 5 days</th>
</tr>
</thead>
<tbody>
<tr>
<td>Walking at work= 3.3 METs</td>
<td>3.3<em>30</em>5 = 495 MET-minutes/week</td>
</tr>
<tr>
<td>Cycling for transportation= 6.0 METs</td>
<td>6.0<em>30</em>5 = 900 MET-minutes/week</td>
</tr>
<tr>
<td>Moderate yard work= 4.0 METs</td>
<td>4.0<em>30</em>5 = 600 MET-minutes/week</td>
</tr>
<tr>
<td>Vigorous intensity in leisure= 8.0 METs</td>
<td>8.0<em>30</em>5 = 1,200 MET-minutes/week</td>
</tr>
<tr>
<td>TOTAL</td>
<td>3,195 MET-minutes/week</td>
</tr>
</tbody>
</table>

Domain Sub Scores

Total MET-minutes/week at work = Walk (METs*min*days) + Mod (METs*min*days) + Vig (METs*min*days) at work

Total MET-minutes/week for transportation = Walk (METs*min*days) + Cycle (METs*min*days) for transportation

Total MET-minutes/week from domestic and garden = Vig (METs*min*days) yard work + Mod (METs*min*days) yard work + Mod (METs*min*days) inside chores

Total MET-minutes/week in leisure-time = Walk (METs*min*days) + Mod (METs*min*days) + Vig (METs*min*days) in leisure-time

Walking, Moderate-Intensity and Vigorous-Intensity Sub Scores

Total Walking MET-minutes/week = Walk MET-minutes/week (at Work + for Transport + in Leisure)

Total Moderate MET-minutes/week = Cycle MET-minutes/week for Transport + Mod MET-minutes/week (Work + Yard chores + Inside chores + Leisure) + Vigorous Yard chores MET-minutes

Note: The above is a total moderate activities only score. If you require a total of all moderate-intensity physical activities you would sum Total Walking and Total Moderate

Total Vigorous MET-minutes/week = Vig MET-minutes/week (at Work + in Leisure)

Total Physical Activity Score

Total Physical Activity MET-minutes/week = Walking MET-minutes/week + Moderate MET-minutes/week + Total Vigorous MET-minutes/week

Continued.............
Also

**Total Physical Activity** MET-minutes/week = Total MET-minutes/week (at Work + for Transport + in Chores + in Leisure)

**Categorical Score - three levels of physical activity are proposed**

1. **Low**
   
   No activity is reported OR
   
   a. Some activity is reported but not enough to meet Categories 2 or 3.

2. **Moderate**
   
   Either of the following 3 criteria
   
   a. 3 or more days of vigorous-intensity activity of at least 20 minutes per day OR
   
   b. 5 or more days of moderate-intensity activity and/or walking of at least 30 minutes per day OR
   
   c. 5 or more days of any combination of walking, moderate-intensity or vigorous-intensity activities achieving a minimum of at least 600 MET-min/week.

3. **High**
   
   Any one of the following 2 criteria.
   
   - Vigorous-intensity activity on at least 3 days and accumulating at least 1500 MET-minutes/week OR
   
   - 7 or more days of any combination of walking, moderate- or vigorous- intensity activities accumulating at least 3000 MET-minutes/week

Please review the full document “Guidelines for the data processing and analysis of the International Physical Activity Questionnaire” for more detailed description of IPAQ analysis and recommendations for data cleaning and processing [www.ipaq.ki.se].
### Appendix L. B2BL Study Attitudes to Exercise Questionnaire

**Born to be Lean (B2BL) Study \nAttitudes to Exercise Questionnaire**

For the questions below tick the column which most applies to you.

<table>
<thead>
<tr>
<th></th>
<th>Strongly disagree</th>
<th>Disagree</th>
<th>Neither agree nor disagree</th>
<th>Agree</th>
<th>Strongly agree</th>
</tr>
</thead>
<tbody>
<tr>
<td>a.</td>
<td>After an exercise session I feel happier about life</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>b.</td>
<td>If I cannot exercise I feel irritable</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>c.</td>
<td>The rest of my life has to fit in around my exercise</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>d.</td>
<td>After an exercise session I feel less stressed</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>e.</td>
<td>I exercise to look attractive</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>f.</td>
<td>After an exercise session I feel that I am a better person</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>g.</td>
<td>If I cannot exercise I feel frustrated</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>h.</td>
<td>I hate not being able to exercise</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>i.</td>
<td>If I do not exercise I feel I cannot cope with everyday life</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>j.</td>
<td>I exercise to control my weight</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>k.</td>
<td>I exercise to be healthy</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>l.</td>
<td>After an exercise session I feel thinner</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>m.</td>
<td>After an exercise session I feel more positive about myself</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>n.</td>
<td>I exercise to feel fit</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>o.</td>
<td>I only exercise to maintain a healthy body weight, but don’t really enjoy it</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>p.</td>
<td>I feel uncomfortable when I exercise so I try to avoid it</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>q.</td>
<td>If I cannot exercise I feel horrible.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>r.</td>
<td>After an exercise session I feel less anxious</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>s.</td>
<td>I am a sporty-type of person</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
### Three-Factor Eating Questionnaire

#### Part I
Please indicate if the statement applies to you by circling the T (true) or F (false).

<table>
<thead>
<tr>
<th>Statement</th>
<th>T</th>
<th>F</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. When I smell a sizzling steak or see a juicy piece of meat, I find it very difficult to keep from eating, even if I have just finished a meal.</td>
<td>T</td>
<td>F</td>
</tr>
<tr>
<td>2. I usually eat too much at social occasions, like parties and picnics</td>
<td>T</td>
<td>F</td>
</tr>
<tr>
<td>3. I am usually so hungry that I eat more than three times a day.</td>
<td>T</td>
<td>F</td>
</tr>
<tr>
<td>4. When I have eaten my quota of calories, I am usually good about not eating any more.</td>
<td>T</td>
<td>F</td>
</tr>
<tr>
<td>5. Dieting is so hard for me because I just get too hungry.</td>
<td>T</td>
<td>F</td>
</tr>
<tr>
<td>6. I deliberately take small helpings as a means of controlling my weight.</td>
<td>T</td>
<td>F</td>
</tr>
<tr>
<td>7. Sometimes things just taste so good that I keep on eating even when I am no longer hungry.</td>
<td>T</td>
<td>F</td>
</tr>
<tr>
<td>8. Since I am often hungry, I sometimes wish that while I am eating, an expert would tell me that I have had enough or that I can have something more to eat.</td>
<td>T</td>
<td>F</td>
</tr>
<tr>
<td>9. When I feel anxious, I find myself eating.</td>
<td>T</td>
<td>F</td>
</tr>
<tr>
<td>10. Life is too short to worry about dieting.</td>
<td>T</td>
<td>F</td>
</tr>
<tr>
<td>11. Since my weight goes up and down, I have gone on reducing diets more than once.</td>
<td>T</td>
<td>F</td>
</tr>
<tr>
<td>12. I often feel so hungry that I just have to eat something.</td>
<td>T</td>
<td>F</td>
</tr>
<tr>
<td>13. When I am with someone who is overeating, I usually overeat too.</td>
<td>T</td>
<td>F</td>
</tr>
<tr>
<td>14. I have a pretty good idea of the number of calories in common food.</td>
<td>T</td>
<td>F</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>---</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>15. Sometimes when I start eating, I just can’t seem to stop.</td>
<td>T</td>
<td>F</td>
</tr>
<tr>
<td>16. It is not difficult for me to leave something on my plate.</td>
<td>T</td>
<td>F</td>
</tr>
<tr>
<td>17. At certain times of the day, I get hungry because I have gotten used to eating then.</td>
<td>T</td>
<td>F</td>
</tr>
<tr>
<td>18. While on a diet, if I eat food that is not allowed, I consciously eat less for a period of time to make up for it.</td>
<td>T</td>
<td>F</td>
</tr>
<tr>
<td>19. Being with someone who is eating often makes me hungry enough to eat also.</td>
<td>T</td>
<td>F</td>
</tr>
<tr>
<td>20. When I feel blue, I often overeat.</td>
<td>T</td>
<td>F</td>
</tr>
<tr>
<td>21. I enjoy eating too much to spoil it by counting calories or watching my weight.</td>
<td>T</td>
<td>F</td>
</tr>
<tr>
<td>22. When I see a real delicacy, I often get so hungry that I have to eat right away.</td>
<td>T</td>
<td>F</td>
</tr>
<tr>
<td>23. I often stop eating when I am not really full as a conscious means of limiting the amount that I eat.</td>
<td>T</td>
<td>F</td>
</tr>
<tr>
<td>24. I get so hungry that my stomach often seems like a bottomless pit.</td>
<td>T</td>
<td>F</td>
</tr>
<tr>
<td>25. My weight has hardly changed at all in the last ten years.</td>
<td>T</td>
<td>F</td>
</tr>
<tr>
<td>26. I am always hungry so it is hard for me to stop eating before I finish the food on my plate.</td>
<td>T</td>
<td>F</td>
</tr>
<tr>
<td>27. When I feel lonely, I console myself by eating.</td>
<td>T</td>
<td>F</td>
</tr>
<tr>
<td>28. I consciously hold back at meals in order not to gain weight.</td>
<td>T</td>
<td>F</td>
</tr>
<tr>
<td>29. I sometimes get very hungry late in the evening or at night.</td>
<td>T</td>
<td>F</td>
</tr>
<tr>
<td>30. I eat anything I want, any time I want.</td>
<td>T</td>
<td>F</td>
</tr>
<tr>
<td>31. Without even thinking about it, I take a long time to eat.</td>
<td>T</td>
<td>F</td>
</tr>
<tr>
<td>32. I count calories as a conscious means of controlling my weight.</td>
<td>T</td>
<td>F</td>
</tr>
<tr>
<td>33. I do not eat some foods because they make me fat.</td>
<td>T</td>
<td>F</td>
</tr>
<tr>
<td>34. I am always hungry enough to eat at any time.</td>
<td>T</td>
<td>F</td>
</tr>
</tbody>
</table>
35. I pay a great deal of attention to changes in my figure.  T  F

36. While on a diet, if I eat a food that is not allowed, I often then  T  F
splurge and eat other high calorie foods.

Part II
Please answer the following questions by circling the number above the
response that is appropriate to you.

37. How often are you dieting in a conscious effort to control your weight?
1 rarely  2 sometimes  3 usually  4 always

38. Would a weight fluctuation of 5 lbs affect the way you live your life?
1 not at all  2 slightly  3 moderately  4 very much

39. How often do you feel hungry?
1 only at mealtimes  2 sometimes between meals  3 often between meals  4 always

40. Do your feelings of guilt about overeating help you to control your food
intake?
1 never  2 rarely  3 often  4 always

41. How difficult would it be for you to stop eating halfway through dinner and
not eat for the next four hours?
1 easy  2 slightly difficult  3 moderately difficult  4 very difficult

42. How conscious are you of what you are eating?
1 not at all  2 slightly  3 moderately  4 extremely

43. How frequently do you avoid ‘stocking up’ on tempting foods?
1 almost never  2 seldom  3 usually  4 almost always

44. How likely are you to shop for low calorie foods?
1 unlikely  2 slightly unlikely  3 moderately likely  4 very likely

45. Do you eat sensibly in front of others and splurge alone?
1 never  2 rarely  3 often  4 always
46. How likely are you to consciously eat slowly in order to cut down on how much YOU eat?
1 unlikely  2 slightly likely  3 moderately likely  4 very likely

47. How frequently do you skip dessert because you are no longer hungry?
1 almost never  2 seldom  3 at least once a week  4 almost every day

48. How likely are you to consciously eat less than you want?
1 unlikely  2 slightly likely  3 moderately likely  4 very likely

49. Do you go on eating binges though you are not hungry?
1 never  2 rarely  3 sometimes  4 at least once a week

50. On a scale of 0 to 5, where 0 means no restraint in eating (eating whatever you want, whenever you want it) and 5 means total restraint (constantly limiting food intake and never ‘giving in’), what number would you give yourself

0 eat whatever you want, whenever you want it

1 usually eat whatever you want, whenever you want it

2 often eat whatever you want, whenever you want it

3 often limit food intake, but often ‘give in’

4 usually limit food intake, rarely ‘give in’

5 constantly limiting food intake, never ‘giving in’

51. To what extent does this statement describe your eating behavior? ‘I start dieting in the morning, but because of any number of things that happen during the day, by evening I have given up and eat what I want, promising myself to start dieting again tomorrow.’

1 not like me  2 little like me  3 pretty good  4 describes me perfectly

description of me

310
Scoring of the Three Factor Eating Questionnaire (TFEQ):

One point is given for each item in Part I.

Part I:

<table>
<thead>
<tr>
<th>Correct Answer</th>
<th>Factor Number</th>
<th>Item Numbers</th>
</tr>
</thead>
<tbody>
<tr>
<td>T</td>
<td>1</td>
<td>4, 6, 14, 18, 23, 28, 32, 33, 35</td>
</tr>
<tr>
<td>F</td>
<td>1</td>
<td>10, 21, 30</td>
</tr>
<tr>
<td>T</td>
<td>2</td>
<td>1, 2, 7, 9, 11, 13, 15, 20, 27, 36</td>
</tr>
<tr>
<td>F</td>
<td>2</td>
<td>16, 25, 31</td>
</tr>
<tr>
<td>T</td>
<td>3</td>
<td>3, 5, 8, 12, 17, 19, 22, 24, 26, 29, 34</td>
</tr>
</tbody>
</table>

Part II:

One point is given for each item (numbered question) in Part II. The direction of the question in Part II is determined by splitting the responses in the middle. If the time is labeled ‘+’, those responses above the middle are given a zero. Vice versa for those with a ‘-’. For example, anyone scoring 3 or 4 on the first item in Part II (item No.37) would receive one point. Anyone scoring 1 or 2 would receive a zero.

<table>
<thead>
<tr>
<th>Direction</th>
<th>Factor Number</th>
<th>Item Number/s</th>
</tr>
</thead>
<tbody>
<tr>
<td>+</td>
<td>1</td>
<td>37, 38, 40, 42, 43, 44, 46, 48, 50</td>
</tr>
<tr>
<td>+</td>
<td>2</td>
<td>45, 49, 51</td>
</tr>
<tr>
<td>+</td>
<td>3</td>
<td>39, 41</td>
</tr>
<tr>
<td>-</td>
<td>3</td>
<td>47</td>
</tr>
</tbody>
</table>

Factor Number:
1 = Restrained Eating
2 = Disinhibition
3 = Hunger
Table N(i). Daily energy and energy-yielding nutrient intakes of obesity resistant individuals (ORI) and obesity susceptible individuals (OSI) with low energy reporters (LER) (n=3) removed with* and without adjustment for percentage body fat (%BF).

<table>
<thead>
<tr>
<th>Nutrient</th>
<th>ORI</th>
<th>OSI</th>
<th>Estimated difference between ORI and OSI adjusted for sex (95%CI)</th>
<th>P-value for sex (adjusted for ORS category)</th>
<th>P-value for ORS category (adjusted for sex)</th>
<th>*Estimated difference between ORI and OSI adjusted for sex (95%CI)</th>
<th>*P-value for sex (adjusted for ORS category)</th>
<th>*P-value for ORS category (adjusted for sex)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Females</td>
<td>Males</td>
<td>Females</td>
<td>Males</td>
<td>Females</td>
<td>Males</td>
<td>Females</td>
<td>Males</td>
</tr>
<tr>
<td>Energy [kJ]</td>
<td>10468 (8901, 12035)</td>
<td>13408 (11482, 15333)</td>
<td>8463 (7498, 9428)</td>
<td>13406 (11293, 15520)</td>
<td>-1050 (-2761, 661)</td>
<td>&lt;0.001</td>
<td>0.199</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Protein (g)</td>
<td>148 (132, 164)</td>
<td>179 (158, 200)</td>
<td>178 (161, 195)</td>
<td>160 (145, 174)</td>
<td>1.3 (-0.3, 2.9)</td>
<td>0.840</td>
<td>0.113</td>
<td>1.5 (-0.8, 3.9)</td>
</tr>
<tr>
<td>Fat (g)</td>
<td>95 (78, 112)</td>
<td>122 (103, 142)</td>
<td>80 (64, 97)</td>
<td>130 (73, 187)</td>
<td>-4 (-32, 25)</td>
<td>0.011</td>
<td>0.787</td>
<td>-62 (-85, -39)</td>
</tr>
<tr>
<td>CHO (g)</td>
<td>490 (452, 52.7)</td>
<td>46.4 (43.6, 49.3)</td>
<td>44.3 (39.7, 48.9)</td>
<td>44.9 (39.3, 50.4)</td>
<td>-3.2 (-7.3, 0.9)</td>
<td>0.568</td>
<td>0.126</td>
<td>2.2 (-3.5, 7.8)</td>
</tr>
<tr>
<td>Alcohol (g)</td>
<td>5 (0, 10)</td>
<td>6 (0, 13)</td>
<td>6 (0, 12)</td>
<td>17 (3, 32)</td>
<td>6 (2, 14)</td>
<td>0.123</td>
<td>0.155</td>
<td>8 (-4, 20)</td>
</tr>
<tr>
<td>Sugar (g)</td>
<td>158 (123, 193)</td>
<td>173 (139, 208)</td>
<td>121 (99, 143)</td>
<td>160 (133, 186)</td>
<td>-26 (-57, 5)</td>
<td>0.012</td>
<td>0.102</td>
<td>21 (-42, 47)</td>
</tr>
<tr>
<td>SFA (g)</td>
<td>40 (31, 49)</td>
<td>46 (37, 55)</td>
<td>30 (24, 36)</td>
<td>60 (26, 94)</td>
<td>1 (-15, 17)</td>
<td>0.043</td>
<td>0.087</td>
<td>9 (-32, 14)</td>
</tr>
<tr>
<td>MUFA (g)</td>
<td>139 (118, 15.9)</td>
<td>12.6 (11.2, 13.9)</td>
<td>128 (109, 148)</td>
<td>148 (108, 196)</td>
<td>0.5 (-21, 3.1)</td>
<td>0.928</td>
<td>0.691</td>
<td>-2 (-5.6, 1.7)</td>
</tr>
<tr>
<td>PUFA (g)</td>
<td>112 (97, 127)</td>
<td>12.8 (11.7, 14.0)</td>
<td>123 (101, 145)</td>
<td>107 (88, 126)</td>
<td>-0.4 (-2.1, 1.3)</td>
<td>0.805</td>
<td>0.624</td>
<td>-3 (-5.5, -0.9)</td>
</tr>
</tbody>
</table>

All values are means (95%CI), **no adjustment for %BF %BF: percentage body fat; BM: body mass; CHO: carbohydrate; CI: confidence interval, LER: low energy reporters, MUFA: monounsaturated fat, ORI: obesity resistant individuals, ORS: obesity resistance/susceptibility, OSI: obesity susceptible individuals, n: number, PUFA: polyunsaturated fat, SFA: saturated fat, TEI: total energy intake
Table N(ii). Daily cholesterol, fibre and selected micronutrient intake per 1000 kJ of energy intake of obesity resistant individuals (ORI) and obesity susceptible individuals (OSI) with low energy reporters (LER) (n=3) removed with* and without adjustment for percentage body fat (%BF).

<table>
<thead>
<tr>
<th>Nutrient</th>
<th>ORI Females</th>
<th>ORI Males</th>
<th>OSI Females</th>
<th>OSI Males</th>
<th>Estimated difference between ORI and OSI, adjusted for sex (95%CI)</th>
<th>P-value for sex (adjusted for ORS category)</th>
<th>P-value for ORS category (adjusted for sex)</th>
<th>*Estimated difference between ORI and OSI, adjusted for sex (95%CI)</th>
<th>*P-value for sex (adjusted for ORS category)</th>
<th>*P-value for ORS category (adjusted for sex)</th>
</tr>
</thead>
<tbody>
<tr>
<td>n</td>
<td>15</td>
<td>15</td>
<td>13</td>
<td>11</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cholesterol (mg.1000 kJ⁻¹)</td>
<td>22 (19, 26)</td>
<td>28 (22, 34)</td>
<td>31 (23, 39)</td>
<td>29 (21, 37)</td>
<td>5 [-2, 11]</td>
<td>0.467</td>
<td>0.142</td>
<td>0 [-9, 10]</td>
<td>0.180</td>
<td>0.900</td>
</tr>
<tr>
<td>Fibre (g.1000 kJ⁻¹)</td>
<td>3.1 (2.6, 3.6)</td>
<td>2.9 (2.4, 3.4)</td>
<td>3.3 (2.8, 3.8)</td>
<td>2.9 (2.1, 3.7)</td>
<td>0.1 (-0.5, 0.7)</td>
<td>0.377</td>
<td>0.703</td>
<td>0.5 (-0.3, 1.3)</td>
<td>0.149</td>
<td>0.254</td>
</tr>
<tr>
<td>Calcium (mg.1000 kJ⁻¹)</td>
<td>109 (90, 128)</td>
<td>101 (85, 117)</td>
<td>134 (104, 164)</td>
<td>94 (75, 114)</td>
<td>10 (-12, 32)</td>
<td><strong>0.048</strong></td>
<td>0.371</td>
<td>22 (-10, 53)</td>
<td><strong>0.031</strong></td>
<td>0.176</td>
</tr>
<tr>
<td>Iron (mg.1000 kJ⁻¹)</td>
<td>1.4 (1.2, 1.6)</td>
<td>1.4 (1.2, 1.6)</td>
<td>1.5 (1.4, 1.7)</td>
<td>1.3 (1.1, 1.5)</td>
<td>0 (-0.2, 0.2)</td>
<td>0.342</td>
<td>0.927</td>
<td>0.1 (-0.2, 0.4)</td>
<td>0.263</td>
<td>0.610</td>
</tr>
<tr>
<td>Magnesium (mg.1000 kJ⁻¹)</td>
<td>37 (32, 42)</td>
<td>38 (33, 44)</td>
<td>44 (37, 51)</td>
<td>35 (27, 43)</td>
<td>2 (-4, 9)</td>
<td>0.297</td>
<td>0.465</td>
<td>10 (1, 19)</td>
<td><strong>0.020</strong></td>
<td><strong>0.025</strong></td>
</tr>
<tr>
<td>Zinc (mg.1000 kJ⁻¹)</td>
<td>1.0 (0.9, 1.2)</td>
<td>1.2 (1.1, 1.4)</td>
<td>1.3 (1.2, 1.4)</td>
<td>1.1 (1.0, 1.2)</td>
<td>0.1 (-0.1, 0.2)</td>
<td>0.767</td>
<td>0.240</td>
<td>0.1 (-0.1, 0.3)</td>
<td>0.737</td>
<td>0.496</td>
</tr>
<tr>
<td>Thiamin (mg.1000 kJ⁻¹)</td>
<td>0.18 (0.13, 0.23)</td>
<td>0.18 (0.13, 0.23)</td>
<td>0.17 (0.13, 0.22)</td>
<td>0.18 (0.12, 0.23)</td>
<td>-0.01 (-0.06, 0.04)</td>
<td>0.981</td>
<td>0.803</td>
<td>0.02 (-0.06, 0.09)</td>
<td>0.591</td>
<td>0.638</td>
</tr>
<tr>
<td>Vitamin A (μg.1000 kJ⁻¹)</td>
<td>105 (82, 127)</td>
<td>92 (66, 119)</td>
<td>138 (106, 170)</td>
<td>121 (74, 168)</td>
<td>31 (0, 63)</td>
<td>0.352</td>
<td><strong>0.050</strong></td>
<td>61 (16, 105)</td>
<td>0.062</td>
<td><strong>0.008</strong></td>
</tr>
<tr>
<td>Vitamin C (mg.1000 kJ⁻¹)</td>
<td>11 (8, 14)</td>
<td>11 (7, 14)</td>
<td>12 (9, 16)</td>
<td>9 (5, 12)</td>
<td>0 (-4, 3)</td>
<td>0.357</td>
<td>0.883</td>
<td>2 (-3, 7)</td>
<td>0.115</td>
<td>0.369</td>
</tr>
<tr>
<td>Vitamin E (μg.1000 kJ⁻¹)</td>
<td>1.1 (0.9, 1.3)</td>
<td>1.1 (0.9, 1.2)</td>
<td>1.2 (1.0, 1.5)</td>
<td>1.0 (0.9, 1.1)</td>
<td>0 (-0.2, 0.2)</td>
<td>0.226</td>
<td>0.674</td>
<td>0 (-0.3, 0.3)</td>
<td>0.373</td>
<td>0.813</td>
</tr>
</tbody>
</table>

All values are means (95%CI)
%BF: percentage body fat, CI: confidence interval, LER: low energy reporters, n: number, ORI: obesity resistant individuals, ORS: obesity resistance/susceptibility, OSI: obesity resistant individuals

Estimated difference between ORI and OSI adjusted for sex (95%CI)
*P-value for sex (adjusted for ORS category)
*Estimated difference between ORI and OSI adjusted for sex (95%CI)
*P-value for ORS category (adjusted for sex)
*P-value for sex (adjusted for ORS category)
*P-value for ORS category (adjusted for sex)
**Table N(iii).** Percentage contribution to total energy intake (TEI) from food groups of obesity resistant individuals (ORI) and obesity susceptible individuals (OSI) with low energy reporters (LER) (n=3) removed with* and without adjustment for percentage body fat (%BF).

<table>
<thead>
<tr>
<th>Food Group</th>
<th>ORI Females</th>
<th>ORI Males</th>
<th>OSI Females</th>
<th>OSI Males</th>
<th>Estimated difference between ORI and OSI adjusted for sex (95%CI)</th>
<th>P-value for sex (adjusted for ORS category)</th>
<th>P-value for ORS category (adjusted for sex)</th>
<th>Estimated difference between ORI and OSI adjusted for sex (95%CI)</th>
<th>P-value for sex (adjusted for ORS category)</th>
<th>P-value for ORS category (adjusted for sex)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bread, grains, pasta, cereals &amp; breakfast cereals</td>
<td>21.6 (17.9, 25.4)</td>
<td>25.3 (20.6, 30.0)</td>
<td>18.6 (15.0, 22.2)</td>
<td>24.3 (18.8, 29.9)</td>
<td>-2.1 (-6.5, 2.3)</td>
<td><strong>0.040</strong></td>
<td>0.347</td>
<td>0.8 (-5.6, 7.1)</td>
<td>0.390</td>
<td>0.808</td>
</tr>
<tr>
<td>Fruit</td>
<td>7.1 (4.8, 9.4)</td>
<td>6.4 (4.2, 8.7)</td>
<td>6.5 (4.0, 9.0)</td>
<td>4.4 (1.1, 7.8)</td>
<td>-1.3 (-3.8, 1.3)</td>
<td>0.324</td>
<td>0.315</td>
<td>2.1 (-1.3, 5.6)</td>
<td><strong>0.014</strong></td>
<td>0.224</td>
</tr>
<tr>
<td>Vegetables</td>
<td>3.8 (2.1, 5.5)</td>
<td>2.3 (1.3, 3.4)</td>
<td>4.3 (2.6, 6.1)</td>
<td>3.1 (1.1, 5.0)</td>
<td>0.6 (0.2, 2.2)</td>
<td>0.087</td>
<td>0.435</td>
<td>15 (-0.8, 3.8)</td>
<td><strong>0.045</strong></td>
<td>0.185</td>
</tr>
<tr>
<td>Milk, cheese &amp; dairy products</td>
<td>14.4 (11.0, 17.8)</td>
<td>10.9 (7.6, 14.1)</td>
<td>15.6 (11.8, 19.5)</td>
<td>11.6 (6.3, 16.8)</td>
<td>1.0 (-2.9, 4.8)</td>
<td>0.054</td>
<td>0.608</td>
<td>2.1 (-3.5, 7.8)</td>
<td>0.067</td>
<td>0.452</td>
</tr>
<tr>
<td>Butter, margarine, fats &amp; oils</td>
<td>5.0 (3.5, 6.5)</td>
<td>4.0 (1.8, 6.1)</td>
<td>4.9 (2.9, 7.0)</td>
<td>5.5 (1.6, 9.5)</td>
<td>0.7 (-1.7, 3.1)</td>
<td>0.786</td>
<td>0.561</td>
<td>-2.4 (-5.7, 0.90)</td>
<td>0.164</td>
<td>0.151</td>
</tr>
<tr>
<td>Meat, poultry, fish &amp; seafood</td>
<td>7.4 (5.0, 9.9)</td>
<td>8.8 (6.4, 11.1)</td>
<td>11.2 (7.7, 14.6)</td>
<td>10.9 (6.8, 15.0)</td>
<td>3.0 (0, 6.0)</td>
<td>0.689</td>
<td>0.053</td>
<td>2.1 (-2.3, 6.5)</td>
<td>0.507</td>
<td>0.350</td>
</tr>
<tr>
<td>Sausages &amp; processed meat</td>
<td>2.1 (0.1, 4.1)</td>
<td>2.8 (1.2, 4.4)</td>
<td>1.2 (0.2, 2.3)</td>
<td>4.1 (1.6, 6.5)</td>
<td>0.2 (-1.7, 2.0)</td>
<td>0.073</td>
<td>0.865</td>
<td>-4.7 (-3.4, 1.9)</td>
<td>0.051</td>
<td>0.587</td>
</tr>
<tr>
<td>Cakes, biscuits, puddings, sugar &amp; confectionery</td>
<td>18.2 (12.6, 23.0)</td>
<td>13.4 (6.4, 20.3)</td>
<td>10.2 (6.2, 14.1)</td>
<td>9.8 (4.7, 14.9)</td>
<td>-5.9 (-11.6, -0.2)</td>
<td>0.32</td>
<td><strong>0.044</strong></td>
<td>-5.5 (-13.9, 2.9)</td>
<td>0.394</td>
<td>0.196</td>
</tr>
<tr>
<td>Nuts &amp; seeds</td>
<td>3.6 (0.5, 6.7)</td>
<td>2.6 (0.7, 4.4)</td>
<td>3.2 (1.4, 5.0)</td>
<td>0.8 (0, 2.0)</td>
<td>-1.1 (-3.3, 1.2)</td>
<td>0.146</td>
<td>0.342</td>
<td>-8.8 (-4.1, 2.5)</td>
<td>0.206</td>
<td>0.627</td>
</tr>
<tr>
<td>Snack foods</td>
<td>3.2 (1.6, 4.8)</td>
<td>3.2 (1.3, 5.0)</td>
<td>2.9 (0.4, 5.5)</td>
<td>1.9 (0, 4.0)</td>
<td>-0.7 (-2.8, 1.3)</td>
<td>0.651</td>
<td>0.470</td>
<td>-1.6 (-4.5, 1.4)</td>
<td>0.879</td>
<td>0.284</td>
</tr>
<tr>
<td>Fast Foods</td>
<td>2.0 (0.4, 3.6)</td>
<td>8.9 (3.3, 14.5)</td>
<td>6.6 (4.1, 9.4)</td>
<td>6.2 (1.6, 10.8)</td>
<td>1.2 (-0.9, 3.3)</td>
<td>0.079</td>
<td>0.561</td>
<td>-1.8 (-7.6, 4.1)</td>
<td><strong>0.027</strong></td>
<td>0.553</td>
</tr>
<tr>
<td>Juice &amp; sweetened beverages</td>
<td>3.6 (1.6, 5.6)</td>
<td>2.9 (1.8, 4.0)</td>
<td>2.7 (0.7, 4.7)</td>
<td>4.5 (2.1, 6.8)</td>
<td>0.3 (1.6, 2.2)</td>
<td>0.677</td>
<td>0.760</td>
<td>0.7 (2.1, 3.4)</td>
<td>0.914</td>
<td>0.619</td>
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</table>

All values are means (95%) Additional food groups were removed from analysis if they contributed < 3%TEI (eggs; hot beverages & water; meat alternatives; savoury sauces & spreads; potato, kumara & taro) %BF: percentage body fat; CI: confidence interval; LER: low energy reporters; n: number; ORI: obesity resistant individuals; ORS: obesity resistance/susceptibility; OSI: obesity individuals; TEI: total energy intake
Appendix O. IceT Study Participant Recruitment Advertisements

Advertisement for obesity resistant individuals (ORI)
Advertisement for obesity susceptible individuals (OSI)

Ice Tea Study

No matter how little you eat, is maintaining your body weight difficult?
Does it seem like you only have to look at food to gain weight?

The Department of Human Nutrition is looking for volunteers to participate in a study to see if people who maintain their weight with relative ease differ in their dietary compensation capabilities to those who struggle to maintain their weight.

You will be required to consume a green ice tea beverage daily for 8 weeks, have blood tests to measure your blood cholesterol levels and have a DEXA scan. You will be remunerated for your time.

If you are a woman aged 20-45 years or man aged 20-55 years and would like further information please contact:

Rebecca Cooke
Department of Human Nutrition
Tel 479 7559
Email icetea.study@otago.ac.nz

This study has been approved by the Human Ethics Committee of the University of Otago.
Appendix P. IceT Study Ethical Approval

Dr R Brown  
Department of Human Nutrition  
Division of Sciences  

12 January 2010  

Dear Dr Brown  

I am again writing to you concerning your proposal entitled “The ICE Tea study (Impact on conservers and spenders)”, Ethics Committee reference number 09/206.

Thank you for sending to me a letter addressing the comments from the Committee. You have provided the Committee with an updated Information Sheet, Consent Form, and evidence that consultation is underway with the Ngāi Tahu Research Consultation Committee.

On the basis of this response, I am pleased to confirm that the proposal now has full ethical approval to proceed.

Approval is for up to three years. If this project has not been completed within three years from the date of this letter, re-approval must be requested. If the nature, consent, location, procedures or personnel of your approved application change, please advise me in writing.

Yours sincerely,

Mr Gary Witte  
Manager, Academic Committees  
Tel: 479 8256  
Email: gary.witte@otago.ac.nz  

cc. Professor C M Skeaff  
Head Department of Human Nutrition
INFORMATION SHEET FOR PARTICIPANTS

Thank you for showing an interest in this project. Please read this information sheet carefully before deciding whether or not to participate. If you decide to participate we thank you. If you decide not to take part there will be no disadvantage to you of any kind and we thank you for considering our request.

What is the Aim of the Project?
Some people appear to have a physiological compensation mechanism that prevents them from overeating. Dietary recommendations should differ depending on whether someone has this innate mechanism or not. The aim of this project is to investigate the characteristics of individuals who appear to compensate and those that do not. Based on information obtained from this study, we should be able to give tailored individual dietary advice.

What Type of Participants are being sought?
We are seeking males (aged 20-55 years) and females (aged 20-45 years) who either struggle to maintain a healthy body weight or maintain a healthy body weight with ease (and may even struggle to gain weight).
People who are in one or more of the categories listed below will not be able to participate in the project:

- People with chronic disease such as cancer, heart disease or diabetes
- People with a medical condition that may affect their metabolic rate eg thyroid dysfunction
- People with phenylketonuria
- Smokers
- Post-menopausal females

What will Participants be Asked to Do?
Should you agree to take part in this project, you will be asked to complete a screening questionnaire. If you are eligible for the study you will be randomised to receive one of two green tea beverages and asked to consume 500ml daily for an eight week period. One beverage will contain 59 grams of carbohydrate and the other <1 gram. We will monitor your blood cholesterol levels and body composition over the study period. You will be asked to attend 9 clinic visits:
Visit 1:
At your first clinic visit in the Department of Human Nutrition a fasting blood sample will be taken by a registered nurse to measure blood cholesterol levels. Prior to the fasting blood tests, you will not be able to have any food or drink (except water) for 12 hours. You will also be asked to refrain from consuming alcohol and performing strenuous exercise the night before the test. During this visit we will also record your height and weight and you will be given instructions on how to collect a 4-day diet record. This food record will be completed over 3 week days and 1 weekend day. You will also be given instructions on how to use an accelerometer to monitor physical activity. You will be asked to wear the accelerometer for seven days. Visit 1 will take approximately 30 minutes. You will be supplied with breakfast at the end of the visit.

Visit 2:
At this visit you will be asked to go to the 9th floor of the Dunedin Public Hospital (DXA scanner suite) to have a DXA scan. We will ask you to lie on a bed for a scan taken with a special DXA scanner, which measures your body composition and bone density. This involves a very small dose of radiation (2uSv), which is less than 1/10th of the radiation received in a single normal chest X-ray. In comparison people living in New Zealand each receive about 2000uSv over a year from natural background radiation. This visit will take approximately 30 minutes.

Visit 3 (week 0):
At visit 3 you will be asked to return your 4-day diet record, electronic scales, and accelerometer. You will be given your first 2 week’s supply of study beverage (green ice tea) and be asked to consume one drink per day between 8:00am and 8:00pm and to return any beverage that was not consumed. This visit will take 10 minutes.

Visit 4 (week 2) and 5 (week 4):
You will be asked to come to the Department of Human Nutrition once a fortnight to collect 2 week’s supply of study beverages (green ice tea) and to return any beverage that was not consumed. Each visit will take approximately 5 minutes.

Visit 6 (week 6):
As well as collecting the next week’s supply of study beverages (green ice tea), you will be asked to complete another 4-day diet record (including 3 week days and 1 weekend day). You will also be asked to wear an accelerometer again for 7 days to monitor physical activity.

Visit 7 (week 7):
You will collect your final (8th) week’s study beverages (green ice tea), and return your 4-day diet record, electronic scales and accelerometer.

Visit 8 (week 8):
At this visit we will take a fasting blood sample to measure blood cholesterol levels. You will be supplied with breakfast at the end of the visit. During this
visit you will also be asked to complete two questionnaires about your eating habits. This visit should take approximately 30 minutes.

Visit 9 (week 8):
At this final visit you will be asked to go to the 9th floor of the Dunedin Public Hospital (DXA scanner suite) to have another DXA scan.

There are 2 methods of disposal of blood samples at the end of the study. You may choose to have any remaining samples disposed of using standard disposal methods or disposed of with an appropriate karakia (Maori blessing). You may also request the return of your blood samples at the end of the study. Please tick the appropriate box on the consent form.

Potential Discomfort
One may experience slight discomfort from the blood tests. Further, there may be some slight bruising. If bruising does occur, it will disappear within one day. On rare occasions some individuals may feel unwell during or after testing. We have a bed for these individuals to rest on and our research nurse will monitor the situation. If you feel unwell during or after testing you will be provided with a ride home.

Can Participants Change their Mind and Withdraw from the Project?
You may withdraw from participation in the project at any time and without any disadvantage to yourself of any kind.

What Data or Information will be Collected and What Use will be Made of it?
We will be collecting personal information regarding your sex, age, weight and height, and body composition. The purpose of collecting this information is so that we are able to describe the overall characteristics of the study population. Only Rachel Brown, Rebecca Cooke, Paula Skidmore and Rachael Taylor will have access to personal information and even then only ID numbers will identify individuals. Participants will be given their personal results along with a brief written interpretation of these at the end of the study. The results of this project may be published. Any data will in no way be linked to any specific participant. The data collected will be securely stored in such a way that only those mentioned above will be able to gain access to it. At the end of the project any personal information will be destroyed immediately except that, as required by the University's research policy, any raw data on which the results of the project depend will be retained in secure storage for five years, after which it will be destroyed.

Reasonable precautions will be taken to protect and destroy data gathered by email. However, the security of electronically transmitted information cannot be
guaranteed. Caution is advised in the electronic transmission of sensitive material.

What if Participants have any Questions?
If you have any questions about our project, either now or in the future, please feel free to contact either:-
Rebecca Cooke                       or  Dr Rachel Brown
Department of Human Nutrition       Department of Human Nutrition
University Phone Number:- 479 7559       University Phone Number:- 479 5839

This study has been approved by the University of Otago Human Ethics Committee.

If you have any concerns about the ethical conduct of the research you may contact the Committee through the Human Ethics Committee Administrator (ph 03 479 8256). Any issues you raise will be treated in confidence and investigated and you will be informed of the outcome.
CONSENT FORM FOR PARTICIPANTS

I have read the Information Sheet concerning this project and understand what it is about. All my questions have been answered to my satisfaction. I understand that I am free to request further information at any stage.

I know that:-

1. My participation in the project is entirely voluntary;

2. I am free to withdraw from the project at any time without any disadvantage;

3. Personal identifying information will be destroyed at the conclusion of the project but any raw data on which the results of the project depend will be retained in secure storage for five years, after which they will be destroyed.

Please indicate the following:

• I consent to any remaining samples being disposed of using standard disposal methods at the end of the study YES / NO

• I wish to have any remaining samples disposed with appropriate karakia (Maori blessing) at the end of the study YES / NO

• I wish to have any remaining samples returned to me at the end of the study YES / NO

4. I may experience slight discomfort during the blood test, and some bruising may occur.

5. I will receive $40 at the completion of the study to cover my travel/parking costs.

6. The results of the project may be published and will be available in the University of Otago Library (Dunedin, New Zealand) but every attempt will be made to preserve my anonymity.
I agree to take part in this project.

.................................................................

.............................................
(Signature of participant)
(Date)

This study has been approved by the University of Otago Human Ethics Committee.

If you have any concerns about the ethical conduct of the research you may contact the Committee through the Human Ethics Committee Administrator (ph 03 479 8256). Any issues you raise will be treated in confidence and investigated and you will be informed of the outcome.
Appendix S. IceT Study 4DDR Instructions for Participants and Recording Sheet

Study ID:________________

The ICE Tea Study

4-Day Diet Record

Department of Human Nutrition
University of Otago
Instructions

We would like you to record in this booklet EVERYTHING you eat or drink for 4 days of the next week (including 1 weekend day and 3 weekdays).

Writing down everything that you eat and drink can be inconvenient but please try not to change what you consume because you are keeping a record.

Describing Foods and Drinks
The more detail you are able to give about the food and drink you have consumed, the better we are able to estimate your nutrient intake.

You need to describe 3 things:
• When you eat
• What you eat
• How much you eat

WHEN YOU EAT
• Simply record the time you eat or drink in the appropriate column.

WHAT YOU EAT
Brand Names
• Please record the brand name of each food, drink or cooking ingredient where possible. If it is convenient staple the wrapper to this diet record booklet.

Additions to Foods/Drinks
• Please describe each item you consume, including any additions to the foods/drinks eg salt, sugar, milk, spices and sauces you have added before eating

Cooking Method
• Please describe how the food/drink item was prepared or cooked and any additions that may have occurred before the cooking process.

  e.g. egg fried with 1 tsp of canola oil
  e.g. chicken breast with skin-on, baked in the oven
HOW MUCH YOU EAT
Describing amounts can be difficult. Here are some tips to make it easier for you to estimate the amount of each food of drink you consume.

Electronic Scales
These are the best way to record quantity. It can take a bit of time, but the accuracy is a lot better than some of the other methods. Many people actually prefer to use scales as it is often easy just to put meal components onto the scales and then onto your plate.

Household Measures
Use cups, glasses, spoons etc

  e.g. 2 rounded teaspoons of white sugar
  e.g. 1 level tablespoon of margarine
  e.g. 1 cup cooked basmati rice

Weights Marked on Packages

  e.g. 150g Fresh n Fruity strawberry yoghurt

Photos of Different Serving Sizes of Some Popular Food and Drink Items
You will be provided with a booklet that contains photos of different serving sizes of some popular food and drink items. These can be useful when you go out for a meal and you prefer not to take your scales with you!

  e.g. Barkers strawberry jam, spread B
  e.g. Bran muffin, size C
  e.g. Watties peas, serving size A

Mixed Food Dishes
For mixed food dishes it may be easier to list the total ingredients, then describe the proportion of this recipe you consumed. On a separate piece of paper or at the end of this diet record, write out the recipe, including brand names, amounts and preparation or cooking details. Then on your diet record sheet indicate the proportion of the recipe you consumed.

  e.g. 1 third of Recipe 1

  Recipe 1 – Creamy Chicken Pasta
  200g Diamond penne pasta (cooked weight)
  50g mushrooms
  200g grilled chicken breast
  2 tsp olive oil
  1 cup Carnation lite canned evaporated milk
  40g grated cheese

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**Sample Record Sheet**

Please record **ALL** food and drink consumed during the whole day, including snacks and water. Remember to report any **ADDITIONS** to each food or drink such as milk, sugar, sauce or spreads.

<table>
<thead>
<tr>
<th>Time</th>
<th>Food or Drink</th>
<th>Brand and Details</th>
<th>Preparation/Cooking</th>
<th>Quantity</th>
</tr>
</thead>
<tbody>
<tr>
<td>10am</td>
<td>Toast slice bread</td>
<td>Molenberg multigrain</td>
<td>Toasted</td>
<td>2 slices - 74 g</td>
</tr>
<tr>
<td></td>
<td>Butter</td>
<td>Anchor</td>
<td></td>
<td>2 tsp</td>
</tr>
<tr>
<td></td>
<td>Strawberry jam</td>
<td>Pams</td>
<td></td>
<td>Spread B</td>
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<tr>
<td></td>
<td>Instant coffee</td>
<td>Nescafe</td>
<td></td>
<td>1 tsp</td>
</tr>
<tr>
<td></td>
<td>Water</td>
<td></td>
<td></td>
<td>200 ml</td>
</tr>
<tr>
<td></td>
<td>Trim milk</td>
<td>Anchor</td>
<td></td>
<td>30 ml</td>
</tr>
<tr>
<td></td>
<td>Sugar</td>
<td></td>
<td></td>
<td>1 tsp</td>
</tr>
<tr>
<td>12pm</td>
<td>Creamy chicken pasta</td>
<td>Homemade- recipe 1</td>
<td></td>
<td>1/3 recipe</td>
</tr>
<tr>
<td></td>
<td>Banana</td>
<td></td>
<td></td>
<td>16 cm long</td>
</tr>
<tr>
<td></td>
<td>Orange juice</td>
<td>McCoy, unsweetened</td>
<td></td>
<td>200 ml</td>
</tr>
</tbody>
</table>

Weigh items on the electronic scales e.g 74 g toast

Record **brand names**. e.g. Anchor, McCoy etc

Use **household measures** to describe amounts of foods such as butter and coffee e.g. teaspoon (tsp), tablespoons (Tbsp), cups (C)

Use a **ruler** to estimate the dimensions e.g. banana – 16 cm long

Write out a **recipe** for a mixed food dish and **record the proportion** consumed eg Creamy Chicken Pasta
<table>
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<th>Time</th>
<th>Food or Drink</th>
<th>Brand and Details</th>
<th>Preparation/Cooking</th>
<th>Quantity</th>
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Day 1 cont.
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<th>Food or Drink</th>
<th>Brand and Details</th>
<th>Preparation/Cooking</th>
<th>Quantity</th>
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Day 2

Date: ______________________

Time

Quantity

Brand and Details

Preparation/Cooking
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<th>Food or Drink</th>
<th>Brand and Details</th>
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<td>Brand and Details</td>
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<td>Preparation/Cooking</td>
<td>Quantity</td>
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</table>

Day 4 cont ______________________

Date: ____________________
Recipes: (please write-out or attach any recipes you use here)
Appendix T. IceT Study Accelerometer Instructions

Instructions For Using The Accelerometer

1. You will start wearing the accelerometer on Thursday (26th of August). Please put the accelerometer on immediately after you wake up.

2. It is very important NOT to break the cable ties around the accelerometer over the 7-days as this may affect the proper functioning of the machine.

3. Please remember to wear your accelerometer each day. Put the accelerometer on as soon as you get up and take it off when you go to bed at night.

4. Your last day of wearing the accelerometer will be Wednesday (1st of September). Before you go to sleep, take off the accelerometer and place it somewhere that is easy for you to remember to bring it back the next day.

5. Please return the accelerometer to Rebecca the following Thursday (2nd of September).

6. We will provide you with your accelerometer results at the end of the study after we have analysed the data.

In order for the accelerometer to work properly,

a. Please slide the clip onto a belt, waistband or a horizontal pocket on your pants or jeans – halfway between your belly button and hip, when you are wearing a belt or clothing with a waistband.

b. Please slide the clip onto the waistband of your underwear, when you wear a dress without a sturdy belt or waistband.

REMEMBER:

• The accelerometer is NOT waterproof.

• Please do not wear your accelerometer in the shower.

• Please do not wear your accelerometer when you are swimming.

• Please wear your accelerometer for the whole day (except when showering, bathing or swimming).
HOW TO WEAR YOUR ACCELEROMETER CORRECTLY

INCORRECT

DO NOT carry the accelerometer in your pocket.

DO NOT wear it where your tummy can push it out of place.

DO NOT wear it on a slanted pocket.

CORRECT

DO attach it to a belt, waistband or horizontally hemmed pocket.

DO wear it close to your side, where your tummy won’t interfere.

DO wear it on your waistband, a belt or a horizontal pocket.
Appendix U. IceT Study Beverage Compliance ‘Tick Sheet’ Example

Study ID: ______________

Beverage Instructions

Storage:
- Refrigerate if possible or store in a cool, dry, dark place.

Consumption:
- Drink 1 bottle (500ml) per day between 8:00am and 8:00pm.
- If you forget to drink a bottle or to finish a bottle please make a note on the calendar below:

<table>
<thead>
<tr>
<th>Week 1</th>
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<tbody>
<tr>
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<table>
<thead>
<tr>
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<tbody>
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<table>
<thead>
<tr>
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</thead>
<tbody>
<tr>
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<table>
<thead>
<tr>
<th>Week 4</th>
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</thead>
<tbody>
<tr>
<td>Fri 28/5</td>
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<table>
<thead>
<tr>
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<tbody>
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<table>
<thead>
<tr>
<th>Week 6</th>
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</thead>
<tbody>
<tr>
<td>Fri 11/6</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Week 7</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fri 18/6</td>
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<table>
<thead>
<tr>
<th>Week 8</th>
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</thead>
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<tr>
<td>Fri 25/6</td>
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</table>

Please return this calendar to Rebecca at your last study blood test appointment
Appendix V. IceT Study Beverage Use Questionnaire

StudyID: ______________________

Which of the following statements most accurately describes how you consumed the Ice Tea beverage provided during the study period (please tick all statements that apply):

- I usually drank the Ice Tea provided instead of a drink I would normally have consumed.
- I usually drank the Ice Tea provided instead of food I would normally have consumed.
- I continued to drink as I normally would and usually drank the Ice Tea as an extra drink.
- I continued to eat as I normally would and usually drank the Ice Tea as an extra.
- I usually drank the Ice Tea as part of a main meal.
- I usually drank the Ice Tea quickly (in less than 15 minutes).
- I usually drank the Ice Tea slowly (over a period of 15 minutes to 1 hour).
- I usually drank the Ice Tea sipped throughout the day.

I usually drank the Ice Tea...

- In the morning
- Around lunchtime
- In the early afternoon
- In the late afternoon
- Around dinnertime
- In the early evening

Other (please specify)

________________________________________________________________________
________________________________________________________________________
________________________________________________________________________
________________________________________________________________________
Appendix W. Dutch Eating Behaviour Questionnaire (DEBQ)

StudyID: _________________

For each item, please circle the answer that best characterizes your attitudes or behaviors.

1. When you have put on weight do you eat less than you usually do?

<table>
<thead>
<tr>
<th></th>
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<th>3</th>
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</tr>
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<tbody>
<tr>
<td></td>
<td>Not Relevant</td>
<td>Never</td>
<td>Seldom</td>
<td>Sometimes</td>
<td>Often</td>
<td>Very Often</td>
</tr>
</tbody>
</table>

2. Do you try to eat less at mealtimes than you would like to eat?

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<thead>
<tr>
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</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Never</td>
<td>Seldom</td>
<td>Sometimes</td>
<td>Often</td>
<td>Very Often</td>
</tr>
</tbody>
</table>

3. How often do you refuse food or drink offered you because you are concerned about your weight?

<table>
<thead>
<tr>
<th></th>
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<th>3</th>
<th>4</th>
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<tbody>
<tr>
<td></td>
<td>Never</td>
<td>Seldom</td>
<td>Sometimes</td>
<td>Often</td>
<td>Very Often</td>
</tr>
</tbody>
</table>

4. Do you watch exactly what you eat?

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<thead>
<tr>
<th></th>
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<th>2</th>
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<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Never</td>
<td>Seldom</td>
<td>Sometimes</td>
<td>Often</td>
<td>Very Often</td>
</tr>
</tbody>
</table>

5. Do you deliberately eat foods that are slimming?

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<thead>
<tr>
<th></th>
<th>1</th>
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<th>4</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>Never</td>
<td>Seldom</td>
<td>Sometimes</td>
<td>Often</td>
<td>Very Often</td>
</tr>
</tbody>
</table>

6. When you have eaten too much do you eat less than usual the following day?

<table>
<thead>
<tr>
<th></th>
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<th>4</th>
<th>5</th>
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<tbody>
<tr>
<td></td>
<td>Not Relevant</td>
<td>Never</td>
<td>Seldom</td>
<td>Sometimes</td>
<td>Often</td>
<td>Very Often</td>
</tr>
</tbody>
</table>

7. Do you deliberately eat less in order not to become heavier?

<table>
<thead>
<tr>
<th></th>
<th>1</th>
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<th>4</th>
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</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Never</td>
<td>Seldom</td>
<td>Sometimes</td>
<td>Often</td>
<td>Very Often</td>
</tr>
</tbody>
</table>

8. How often do you try not to eat between meals because you are watching your weight?

<table>
<thead>
<tr>
<th></th>
<th>1</th>
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<th>3</th>
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<tbody>
<tr>
<td></td>
<td>Never</td>
<td>Seldom</td>
<td>Sometimes</td>
<td>Often</td>
<td>Very Often</td>
</tr>
</tbody>
</table>

9. How often in the evenings do you try not to eat because you are watching your weight?

<table>
<thead>
<tr>
<th></th>
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<tbody>
<tr>
<td></td>
<td>Never</td>
<td>Seldom</td>
<td>Sometimes</td>
<td>Often</td>
<td>Very Often</td>
</tr>
</tbody>
</table>
10. Do you take your weight into account with what you eat?

<table>
<thead>
<tr>
<th></th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
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<tbody>
<tr>
<td></td>
<td>Never</td>
<td>Seldom</td>
<td>Sometimes</td>
<td>Often</td>
<td>Very Often</td>
</tr>
</tbody>
</table>

11. Do you have a desire to eat when you are irritated?

<table>
<thead>
<tr>
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<th>2</th>
<th>3</th>
<th>4</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>Not Relevant</td>
<td>Never</td>
<td>Seldom</td>
<td>Sometimes</td>
<td>Often</td>
<td>Very Often</td>
</tr>
</tbody>
</table>

12. Do you have a desire to eat when you have nothing to do?

<table>
<thead>
<tr>
<th></th>
<th>0</th>
<th>1</th>
<th>2</th>
<th>3</th>
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<tbody>
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<td></td>
<td>Not Relevant</td>
<td>Never</td>
<td>Seldom</td>
<td>Sometimes</td>
<td>Often</td>
<td>Very Often</td>
</tr>
</tbody>
</table>

13. Do you have a desire to eat when you are depressed or discouraged?

<table>
<thead>
<tr>
<th></th>
<th>0</th>
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<th>2</th>
<th>3</th>
<th>4</th>
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<tbody>
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<td></td>
<td>Not Relevant</td>
<td>Never</td>
<td>Seldom</td>
<td>Sometimes</td>
<td>Often</td>
<td>Very Often</td>
</tr>
</tbody>
</table>

14. Do you have a desire to eat when you are feeling lonely?

<table>
<thead>
<tr>
<th></th>
<th>0</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>Not Relevant</td>
<td>Never</td>
<td>Seldom</td>
<td>Sometimes</td>
<td>Often</td>
<td>Very Often</td>
</tr>
</tbody>
</table>

15. Do you have a desire to eat when somebody lets you down?

<table>
<thead>
<tr>
<th></th>
<th>0</th>
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<th>2</th>
<th>3</th>
<th>4</th>
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<tbody>
<tr>
<td></td>
<td>Not Relevant</td>
<td>Never</td>
<td>Seldom</td>
<td>Sometimes</td>
<td>Often</td>
<td>Very Often</td>
</tr>
</tbody>
</table>

16. Do you have a desire to eat when you are cross?

<table>
<thead>
<tr>
<th></th>
<th>0</th>
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<th>2</th>
<th>3</th>
<th>4</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>Not Relevant</td>
<td>Never</td>
<td>Seldom</td>
<td>Sometimes</td>
<td>Often</td>
<td>Very Often</td>
</tr>
</tbody>
</table>

17. Do you have a desire to eat when something unpleasant is about to happen?

<table>
<thead>
<tr>
<th></th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Never</td>
<td>Seldom</td>
<td>Sometimes</td>
<td>Often</td>
<td>Very Often</td>
</tr>
</tbody>
</table>

18. Do you get the desire to eat when you are anxious, worried or tense?

<table>
<thead>
<tr>
<th></th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Never</td>
<td>Seldom</td>
<td>Sometimes</td>
<td>Often</td>
<td>Very Often</td>
</tr>
</tbody>
</table>

19. Do you have a desire to eat when things are going against you or have gone wrong?

<table>
<thead>
<tr>
<th></th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Never</td>
<td>Seldom</td>
<td>Sometimes</td>
<td>Often</td>
<td>Very Often</td>
</tr>
</tbody>
</table>

20. Do you have a desire to eat when you are frightened?

<table>
<thead>
<tr>
<th></th>
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<th>2</th>
<th>3</th>
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<td>Never</td>
<td>Seldom</td>
<td>Sometimes</td>
<td>Often</td>
<td>Very Often</td>
</tr>
</tbody>
</table>
21. Do you have a desire to eat when you are disappointed?

<table>
<thead>
<tr>
<th>0</th>
<th>1</th>
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<th>3</th>
<th>4</th>
<th>5</th>
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</thead>
<tbody>
<tr>
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<td>Never</td>
<td>Seldom</td>
<td>Sometimes</td>
<td>Often</td>
<td>Very Often</td>
</tr>
</tbody>
</table>

22. Do you have a desire to eat when you are emotionally upset?

<table>
<thead>
<tr>
<th>0</th>
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<th>4</th>
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</thead>
<tbody>
<tr>
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<td>Never</td>
<td>Seldom</td>
<td>Sometimes</td>
<td>Often</td>
<td>Very Often</td>
</tr>
</tbody>
</table>

23. Do you have a desire to eat when you are bored or restless?

<table>
<thead>
<tr>
<th>0</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Not Relevant</td>
<td>Never</td>
<td>Seldom</td>
<td>Sometimes</td>
<td>Often</td>
<td>Very Often</td>
</tr>
</tbody>
</table>

24. If food tastes good to you do you eat more than usual?

<table>
<thead>
<tr>
<th>0</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Never</td>
<td>Seldom</td>
<td>Sometimes</td>
<td>Often</td>
<td>Very Often</td>
<td></td>
</tr>
</tbody>
</table>

25. If food smells and looks good do you eat more than usual?

<table>
<thead>
<tr>
<th>0</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Never</td>
<td>Seldom</td>
<td>Sometimes</td>
<td>Often</td>
<td>Very Often</td>
<td></td>
</tr>
</tbody>
</table>

26. If you see or smell something delicious do you have a desire to eat it?

<table>
<thead>
<tr>
<th>0</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
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<td>Seldom</td>
<td>Sometimes</td>
<td>Often</td>
<td>Very Often</td>
<td></td>
</tr>
</tbody>
</table>

27. If you have something delicious to eat do you eat it straight away?

<table>
<thead>
<tr>
<th>0</th>
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<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Never</td>
<td>Seldom</td>
<td>Sometimes</td>
<td>Often</td>
<td>Very Often</td>
<td></td>
</tr>
</tbody>
</table>

28. If you see others eating do you also want to eat?

<table>
<thead>
<tr>
<th>0</th>
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<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
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<tbody>
<tr>
<td>Never</td>
<td>Seldom</td>
<td>Sometimes</td>
<td>Often</td>
<td>Very Often</td>
<td></td>
</tr>
</tbody>
</table>

29. Do you eat more than usual when you see others eating?

<table>
<thead>
<tr>
<th>0</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
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</tr>
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<tbody>
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<td>Seldom</td>
<td>Sometimes</td>
<td>Often</td>
<td>Very Often</td>
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</tbody>
</table>

30. When preparing a meal are you inclined to eat something?

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<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Never</td>
<td>Seldom</td>
<td>Sometimes</td>
<td>Often</td>
<td>Very Often</td>
<td></td>
</tr>
</tbody>
</table>

31. If you walk past the bakery do you have the desire to buy something delicious?

<table>
<thead>
<tr>
<th>0</th>
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<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Never</td>
<td>Seldom</td>
<td>Sometimes</td>
<td>Often</td>
<td>Very Often</td>
<td></td>
</tr>
</tbody>
</table>
32. If you walk past a snackbar or a cafe do you have the desire to buy something delicious?

<table>
<thead>
<tr>
<th></th>
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<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Never</td>
<td>Seldom</td>
<td>Sometimes</td>
<td>Often</td>
<td>Very Often</td>
</tr>
</tbody>
</table>

33. Can you resist eating delicious food?

<table>
<thead>
<tr>
<th></th>
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<th>4</th>
<th>5</th>
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</thead>
<tbody>
<tr>
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<td>Never</td>
<td>Seldom</td>
<td>Sometimes</td>
<td>Often</td>
<td>Very Often</td>
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</tbody>
</table>

Thank you for completing this questionnaire.

Scoring of the Dutch Eating Behaviour Questionnaire (DEBQ):

Summed totals for each section of questions (Restrained Eating, Emotional Eating and External Eating) are calculated.

<table>
<thead>
<tr>
<th>Section</th>
<th>Item Numbers</th>
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<tbody>
<tr>
<td>Restrained Eating</td>
<td>1*, 2, 3, 4, 5, 6*, 7, 8, 9, 10</td>
</tr>
<tr>
<td>Emotional Eating</td>
<td>11*, 12*, 13*, 14*, 15*, 16*, 17, 18, 19, 20*, 21*, 22*, 23*</td>
</tr>
<tr>
<td>External Eating</td>
<td>24, 25, 26, 27, 28, 29, 30, 31**, 32, 33</td>
</tr>
</tbody>
</table>

* indicates items with a non-relevant response category (0) in addition to the categories never (1), seldom (2), sometimes (3), often (4), and very often (5)

** for this item scoring is reversed
Appendix X. The Intuitive Eating Scale (IES)

StudyID: ____________________

For each item, please circle the answer that best characterizes your attitudes or behaviors.

1. I try to avoid certain foods high in fat, carbohydrates, or calories.
   1   2    3    4    5
   Strongly Disagree    Disagree    Neutral    Agree    Strongly Agree

2. I stop eating when I feel full (not overstuffed).
   1   2    3    4    5
   Strongly Disagree    Disagree    Neutral    Agree    Strongly Agree

3. I find myself eating when I’m feeling emotional (e.g., anxious, depressed, sad), even when I’m not physically hungry.
   1   2    3    4    5
   Strongly Disagree    Disagree    Neutral    Agree    Strongly Agree

4. If I am craving a certain food, I allow myself to have it.
   1   2    3    4    5
   Strongly Disagree    Disagree    Neutral    Agree    Strongly Agree

5. I follow eating rules or dieting plans that dictate what, when, and/or how much to eat.
   1   2    3    4    5
   Strongly Disagree    Disagree    Neutral    Agree    Strongly Agree

6. I find myself eating when I am bored, even when I’m not physically hungry.
   1   2    3    4    5
   Strongly Disagree    Disagree    Neutral    Agree    Strongly Agree

7. I can tell when I’m slightly full.
   1   2    3    4    5
   Strongly Disagree    Disagree    Neutral    Agree    Strongly Agree

8. I can tell when I’m slightly hungry.
   1   2    3    4    5
   Strongly Disagree    Disagree    Neutral    Agree    Strongly Agree

9. I get mad at myself for eating something unhealthy.
   1   2    3    4    5
   Strongly Disagree    Disagree    Neutral    Agree    Strongly Agree
10. I find myself eating when I am lonely, even when I’m not physically hungry.

<table>
<thead>
<tr>
<th>Strongly Disagree</th>
<th>Disagree</th>
<th>Neutral</th>
<th>Agree</th>
<th>Strongly Agree</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
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</tbody>
</table>

11. I trust my body to tell me when to eat.

<table>
<thead>
<tr>
<th>Strongly Disagree</th>
<th>Disagree</th>
<th>Neutral</th>
<th>Agree</th>
<th>Strongly Agree</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
</tbody>
</table>

12. I trust my body to tell me what to eat.

<table>
<thead>
<tr>
<th>Strongly Disagree</th>
<th>Disagree</th>
<th>Neutral</th>
<th>Agree</th>
<th>Strongly Agree</th>
</tr>
</thead>
<tbody>
<tr>
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<td>3</td>
<td>4</td>
<td>5</td>
</tr>
</tbody>
</table>

13. I trust my body to tell me how much to eat.

<table>
<thead>
<tr>
<th>Strongly Disagree</th>
<th>Disagree</th>
<th>Neutral</th>
<th>Agree</th>
<th>Strongly Agree</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
</tbody>
</table>

14. I have forbidden foods that I don’t allow myself to eat.

<table>
<thead>
<tr>
<th>Strongly Disagree</th>
<th>Disagree</th>
<th>Neutral</th>
<th>Agree</th>
<th>Strongly Agree</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2</td>
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<td>4</td>
<td>5</td>
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</tbody>
</table>

15. When I’m eating, I can tell when I am getting full.

<table>
<thead>
<tr>
<th>Strongly Disagree</th>
<th>Disagree</th>
<th>Neutral</th>
<th>Agree</th>
<th>Strongly Agree</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
</tbody>
</table>

16. I use food to help me soothe my negative emotions.

<table>
<thead>
<tr>
<th>Strongly Disagree</th>
<th>Disagree</th>
<th>Neutral</th>
<th>Agree</th>
<th>Strongly Agree</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2</td>
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</tbody>
</table>

17. I find myself eating when I am stressed out, even when I’m not physically hungry.

<table>
<thead>
<tr>
<th>Strongly Disagree</th>
<th>Disagree</th>
<th>Neutral</th>
<th>Agree</th>
<th>Strongly Agree</th>
</tr>
</thead>
<tbody>
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<td>1</td>
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</tbody>
</table>

18. I feel guilty if I eat a certain food that is high in calories, fat, or carbohydrates.

<table>
<thead>
<tr>
<th>Strongly Disagree</th>
<th>Disagree</th>
<th>Neutral</th>
<th>Agree</th>
<th>Strongly Agree</th>
</tr>
</thead>
<tbody>
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<td>1</td>
<td>2</td>
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<td>5</td>
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</tbody>
</table>

19. I think of a certain food as “good”or “bad” depending on its nutritional content.

<table>
<thead>
<tr>
<th>Strongly Disagree</th>
<th>Disagree</th>
<th>Neutral</th>
<th>Agree</th>
<th>Strongly Agree</th>
</tr>
</thead>
<tbody>
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<td>1</td>
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<td>5</td>
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</tbody>
</table>

20. I don’t trust myself around fattening foods.

<table>
<thead>
<tr>
<th>Strongly Disagree</th>
<th>Disagree</th>
<th>Neutral</th>
<th>Agree</th>
<th>Strongly Agree</th>
</tr>
</thead>
<tbody>
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<td>1</td>
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<td>5</td>
</tr>
</tbody>
</table>
21. I don’t keep certain foods in my house/apartment because I think that I may lose control and eat them.

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<tr>
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<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Strongly Disagree</td>
<td>Disagree</td>
<td>Neutral</td>
<td>Agree</td>
<td>Strongly Agree</td>
</tr>
</tbody>
</table>

Scoring of the Intuitive Eating Scale (IES):

Unconditional Permission to Eat Subscale:
- Reverse score items 1, 5, 9, 14, 18, 19, 20, and 21
- Add these reversed scored items with item 4
- Divide this summed total by 9

Eating for Physical Rather than Emotional Reasons Subscale:
- Reverse score items 3, 6, 10, 16, and 17
- Add these reversed scored items with item 2
- Divide this summed total by 6

Reliance on Internal Hunger/Satiety Cues Subscale:
- Add together items 7, 8, 11, 12, 13, and 15
- Divide this summed total by 6

Total Intuitive Eating Score:
- Reverse score items 1, 3, 5, 6, 9, 10, 14, 16, 17, 18, 19, 20, and 21
- Add these reverse scored items with items 2, 4, 7, 8, 11, 12, 13, and 15
- Divide this summed total by 21

Thank you for completing this questionnaire
Appendix Y. Email Invitation Letter to IceT Study Participants to Participate in an
Assessment of Sensitivity to Oral Fatty Acid Ingestion

Hi XXXXXX

Thank you for your participation in the ICE Tea Study.

We would like to carry out one extra test as part of the ICE Tea Study. We would like to invite you to attend a tasting session at the sensory laboratory in the Department of Food Science. This is to measure your fat sensitivity and will determine if you can taste fat at low concentrations. You will be asked to taste 3 different types of milk and 4 different types of custards. This session should take approximately 20 minutes. You will receive a movie pass for your time. Please see attached Information Sheet.

If you agree to take part in this tasting session please choose from the times below your first option, and a second option that would suit you. We will then email you to confirm your time and attach a map of how to get to the session.

Tuesday 29th June, 3pm
Wednesday 30th June, 10.30am
Tuesday 6th July, 10.30am
Thursday 8th July, 3pm
Monday 12th July, 3pm
Friday 16th July, 10.30am

Many thanks

Rebecca Cooke
Appendix Z. Ethical Approval for the Assessment of Sensitivity to Oral Fatty Acid Ingestion

From: Bethany Jackson <beth.jackson@otago.ac.nz>
To: Rachel Brown <rachel.brown@otago.ac.nz>
Cc: Murray Skeaff <murray.skeaff@otago.ac.nz>
Date: 31 May 2010 10:51:48 am NZST
Subject: Ethics application 09/206

Tēnā koe, Rachel

Re: The ICE Tea study (Impact on conservers and expenders)

Thank you for your letter to Gary Witte regarding the amendments you would like to make to the original ethics application. You have notified the Committee about the additional test participants will attend to assess their ability to taste fatty acid.

Your proposal continues to be fully approved by the Human Ethics Committee. If the nature, consent, location, procedures or personnel of your approved application change, please advise Gary Witte in writing. I hope all goes well for you with your upcoming research.

Nāku noa, nā
Beth Jackson

Academic Committees
Clocktower Building
University of Otago

Ph: (03) 479 6531
Fax: (03) 479 8221
email: beth.jackson@otago.ac.nz
INFORMATION SHEET FOR PARTICIPANTS

Sensitivity to Oral Fat Ingestion Study

Thank you for your participation in the ICE tea Study. We would like to carry out one extra test as part of the ICE Tea Study. We would like to invite you to attend a tasting session at the sensory laboratory in the Department of Food Science. This is to measure your fat sensitivity and will determine if you can taste fat at low concentrations. You will be asked to taste 3 different types of milk and 4 different types of custards. This session should take approximately 20 minutes.

If you agree to take part in this tasting session one of the researchers from the ICE Tea Study will then contact you to book you in for the tasting session.

There are several things that you should not do before the tasting session: -

1. No strong tea or coffee 1 hour before the test
2. No strong perfume to be worn to the tasting session
3. No large meal before the tasting session - you should be no more than 70-80% full

The entire tasting session should take approximately 20 minutes. You will receive a movie pass for your time.
Appendix AB. Consent Form for Participants for the Assessment of Sensitivity to Oral Fatty Acid Ingestion

Consent Form

Sensitivity to Oral Fat Ingestion Study

I have read the Information above concerning this project and understand what it is about. All my questions have been answered to my satisfaction. I understand that I am free to request further information at any stage.

I know that:-

1. My participation in the project is entirely voluntary;

2. I am free to withdraw from the project at any time without any disadvantage;

3. Personal identifying information will be destroyed at the conclusion of the project but any raw data on which the results of the project depend will be retained in secure storage for five years, after which they will be destroyed.

4. The results of the project may be published and will be available in the University of Otago Library (Dunedin, New Zealand) but every attempt will be made to preserve my anonymity.

I agree to take part in this project.

Name: ..........................................................................................................

.............................................................................................................

(Signature of participant)     (Date)

This study has been approved by the University of Otago Human Ethics Committee.

If you have any concerns about the ethical conduct of the research you may contact the Committee through the Human Ethics Committee Administrator (ph 03 479 8256). Any issues you raise will be treated in confidence and investigated and you will be informed of the outcome.