Investigating the Eating Behaviours of Free-Living Low-Carbohydrate Diets Users in New Zealand

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Abstract

Background: Many individuals adopt a low-carbohydrate (low-CHO) diet as a weight management approach. Eating behaviours are a crucial determinant of dietary intake and health, however, their relation to low-CHO diet users has scarcely been assessed.

Aim: This study aimed to investigate the body compositions, dietary intakes, and eating behaviours of free-living, self-reported low-CHO diet users in NZ and how they differed between CHO intake groups.

Methods: This cross-sectional study recruited men and women aged 20-45 years following a low-CHO diet for at least four months. Participants completed a health and demographics questionnaire, the Three-Factor Eating Questionnaire (TFEQ), a 4-day weighed dietary record, and provided anthropometric measurements. Participants were grouped into three CHO intake ranges defined as moderately low (ML) (>100 and <150 g/day) (n=10), low (L) (≥50 and <100 g/day) (n=20), and very-low (VL) (<50 g/day of CHO) (n=39).

Results: Sixty-nine individuals with a mean age of 35 years participated in this study. Their mean macronutrient intakes as a contribution to total energy were 12.5 ± 8.28% for CHO, 58 ± 11.3% for total fat, 22.6 ± 6.98% for saturated fatty acids (SFA), and 24.5 (23.3-25.9) % for protein. Total fat and SFA (%EI) increased as CHO intake decreased, while protein intake was similar in each CHO group. They had a mean body fat percentage (BF%) of 27.9 ± 9.9% and a median muscle mass of 28.0 [25.2-33.2] kg. Body composition was similar in each CHO group. Overall, participants showed high restraint, low rigid and flexible restraint, low disinhibition, low habitual, situational, and emotional disinhibition, low hunger, and low internal and external hunger. TFEQ scores did not differ significantly between CHO groups. Restraint was positively associated with CHO (%EI) ($r = 0.34$, $p = <0.01$) and inversely associated with total fat ($r = -0.35$, $p = <0.01$) and SFA (%EI) ($r = -0.31$, $p = 0.01$). CHO intake (%EI) was positively correlated with rigid restraint ($r = 0.27$, $p = <0.01$) and flexible restraint ($r = 0.34$, $p = <0.01$). Restraint correlated with BF% ($r = 0.28$, $p = 0.02$), and each increasing restraint score predicted a 0.6% increase in BF%. As diet duration increased, BMI ($r = -0.27$, $p = 0.03$), WC ($r = -0.28$, $p = 0.03$), and habitual disinhibition ($r = -0.27$, $p = 0.03$) decreased.

Conclusions: Our findings suggest that low-CHO diet users exhibit high dietary restraint, low disinhibition, and low hunger. Restraint may increase as CHO intake increases and fat intake decreases. BF% was

accompanied by high restraint. It is important to consider the associations eating behaviours can have with dietary intake and body composition in low-CHO diets in determining the suitability of such a diet.

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Table of Contents

List of Tables

List of Figures

List of Appendices

Abbreviation List

%EI	Percentage of Energy Intake
ANOVA	Analysis of Variance
ANCOVA	Analysis of Covariance
BF%	Body fat percentage
BFM	Body fat mass
BIA	Bioelectrical Impedance Analysis
BMI	Body Mass Index
BP	Blood Pressure
CHO	Carbohydrate
CVD	Cardiovascular Disease
DXA	Dual X-ray Absorptiometry
ED	Eating Disturbance
EE	Energy Expenditure
EI	Energy Intake
g	Gram(s)
HDL	High-density Lipoprotein
HDQ	Health and Demographics Questionnaire
HNRU	Human Nutrition Research Unit
kcal/d	Kilocalories per day
LCHO	Low Carbohydrate
LDL	Low-density Lipoprotein
MD	Mean Difference
MLCHO	Moderately Low Carbohydrate
MUFA	Monounsaturated Fatty Acids
NZ	New Zealand
NZE	New Zealand European
PUFA	Polyunsaturated Fatty Acids
RCT	Randomised Controlled Trial
SFA	Saturated Fatty Acids
T2DM	Type 2 Diabetes Mellitus
TFEQ	Three Factor Eating Questionnaire
TF	Triglycerides

VLCHO	Very Low Carbohydrate
WC	Waist Circumference

Chapter 1

Introduction

1.1 Background

Obesity in New Zealand (NZ) is a pressing public health concern of substantial magnitude. The latest National Nutrition Survey conducted in NZ in 2008/09 revealed an average body mass index (BMI) of 27.6 kg/m^2 for adults as 37.0% were classified as overweight and 27.8% were classified as obese indicating a notable prevalence of overweight individuals (Ministry of Health, 2011). More recent, self-reported data from the 2020/21 NZ Health Survey indicates that 34% of the population suffers from obesity, with an additional 34% classified as overweight – thus, 68% of the population has excess weight. These figures exhibit an upward trend since 2008/09 and are predicted to continue their ascent (Ministry of Health, 2021). Consequently, it comes as no surprise that over one-third of men and two-thirds of women in NZ have endeavoured to manage their weight through various healthful or potentially harmful practices, such as dietary modifications, increasing physical activity, or the ingestion of laxatives, diuretic pills or diet pills (Utter et al., 2012).

Low-carbohydrate (low-CHO) diets have gained tremendous popularity over recent years as a weight management approach (Oh et al., 2019). These diets revolve around varying degrees of CHO restriction, involving eliminating or reducing plant-based foods such as grains, fruit, and vegetables, which serve as primary sources of CHO (Churuangsuk et al., 2019). Several iterations of the low-CHO diet have emerged, including the Atkins, ketogenic, Zone, and Paleo diets (Fields et al., 2016). Although there is no standardised classification of low-CHO diets, they are typically defined by daily CHO consumption. In general, a low-CHO diet contains ≤150 g of CHO per day (Brouns, 2018; Westman et al., 2007) moderately low contains >100 and <150 g/day (Brouns, 2018), low contains ≥50 and <100 g/day (Bilsborough & Crowe, 2003; Fields et al., 2016), and very-low contains <50 g/day of CHO (Brouns, 2018).

The effectiveness of low-CHO diets for weight management remains a subject of ongoing debate and controversy (Churuangsuk et al., 2018). Low-CHO diets have demonstrated rapid weight loss in the short-term (≤ six months) (Gram-Kampmann et al., 2022; Kakoschke et al., 2021; Romano et al., 2019). However, the evidence is less significant when considering the long-term effects (>six months) (Dyson et al., 2010; Naude et al., 2022; Oh et al., 2019; Silverii et al., 2022). A comprehensive review of meta-analyses revealed that low-quality meta-analyses tend to show favourable weight loss outcomes associated with low-CHO diets. In contrast, high-quality meta-analyses indicate limited or no significant benefits compared to alternative approaches, such as high-CHO low-fat diets (Churuangsuk et al., 2018).

Low-CHO diets have shown favourable changes to body composition, particularly in reducing fat mass (Gram-Kampmann et al., 2022; Perissiou et al., 2020). A low-CHO diet led to more significant reductions in total fat mass percentage compared to a healthy control diet (Gram-Kampmann et al., 2022) and a low-fat diet (Hu et al., 2016). The optimal level of CHO restriction that yields the most effective results has yet to be definitively determined; however, weight loss appears to improve with increasing CHO restriction (Dinu et al., 2020; Ebbeling et al., 2018). Furthermore, compared to a low-fat diet (<30% fat), low-CHO diets may exhibit better adherence (Hu et al., 2016). Meta-analyses indicated that short-term weight loss is observed regardless of whether the diet is low in CHO or balanced in macronutrient composition. There has been minimal or no discernible distinction in weight loss past six months of follow-up when overweight and obese adults are assigned to low-CHO diets or isocaloric balanced weight loss diets (Churuangsuk et al., 2018; Dinu et al., 2020; Naude et al., 2022; Naude et al., 2014). The evidence supporting low-CHO diets for weight management remains inconclusive due to various limitations in the existing literature. Many studies suffer from small sample sizes, short duration, lack of generalisability to broader populations, and employ unstandardised definitions and methodologies (Churuangsuk et al., 2018; Naude et al., 2022; Silverii et al., 2022). These factors contribute to the uncertainty surrounding the efficacy of popular low-CHO diets as a long-term (>six months) weight management strategy.

Eating behaviours encompass the diverse patterns and habits individuals adopt in relation to food consumption, reflecting their approach to nutrition. Eating behaviours profoundly influence dietary choices, weight management, psychological well-being, and overall health (LaCaille, 2020). Understanding eating behaviours can improve physical and mental health and treat conditions such as obesity and disordered eating (Bryant et al., 2019). Eating behaviours have been categorised into three primary factors (Stunkard & Messick, 1985), each comprising various sub-factors: restraint (comprising rigid and flexible), disinhibition (emotional, situational, and habitual), and hunger (internal and external) (Bond et al., 2001; Stunkard & Messick, 1985). Scores classify individuals as either high or low in relation to each factor and sub-factor, and these scores can change over time. Restraint involves a conscious effort to regulate food intake, with rigid restraint characterised by an uncompromising "all-or-nothing" approach with strict rules and the experience of guilt when deviating from these rules. In contrast, flexible restraint allows occasional indulgences without guilt, maintaining mindful control over health-conscious choices. Disinhibition, on the other hand, denotes the loss of control over one's eating behaviour, triggered by various stimuli or cues, which may include emotional states (e.g., sadness or boredom), specific situations and environmental contexts (e.g., social gatherings), or habitual patterns (e.g. late-night snacking). Hunger encompasses the perception and regulation of hunger cues, encompassing internal physiological signals indicating the need for sustenance, such as stomach cramping, as well as external triggers like environmental or social cues (e.g. dinner time), which may prompt eating regardless of genuine physiological hunger (Bond et al., 2001; Stunkard & Messick, 1985).

The three-factor eating questionnaire (TFEQ) is a valuable tool in psychology and nutrition, enabling the quantitative assessment of eating behaviours (Bond et al., 2001; Stunkard & Messick, 1985). This assessment aids in the identification of patterns or habitual tendencies that potentially contribute to weight or health status. The TFEQ has been translated into various languages and adapted for use in different cultural contexts, contributing to its widespread usage. Healthcare professionals, researchers, and psychologist use the insights from such assessments to devise effective and personalised interventions and treatments for individuals seeking support with weight management, eating disorders, or general eating habits.

The existing body of research exploring the association between low-CHO diets and eating behaviour is limited, resulting in a range of outcomes characterised by positive, conflicting, or nonsignificant findings. Low-CHO diets may exert a positive influence on eating behaviours, such as increased restraint (Anguah et al., 2019; Colombarolli et al., 2022; Soenen et al., 2012), reduced disinhibition and hunger (Anguah et al., 2019; Saslow et al., 2014; Soenen et al., 2012), decreased susceptibility to emotional and external cues (Mohorko et al., 2019; Saslow et al., 2014), and reduced cravings for sweet and high-CHO foods (Anguah et al., 2019). However, contrasting evidence exists suggesting potential adverse effects on eating behaviours. Notably, individuals adhering to low-CHO diets may face a heightened risk of experiencing disordered eating patterns, particularly binge eating, and poor control of food cravings compared to non-dieters (Colombarolli et al., 2022; Oliveira et al., 2020). Weight loss diets, in general, may compromise an individual's ability to accurately perceive signals of hunger and satiety, thereby impairing their ability to regulate their eating behaviours, potentially leading to episodes of binge eating and subsequent weight gain (Leong et al., 2016). Further research is warranted to understand better the relationship between low-CHO diets, healthy and unhealthy eating behaviours, and body composition.

1.2 Purpose of the study

Although low-CHO diets have gained significant public interest and popularity, there is limited knowledge about those who follow these diets in NZ. Previous work has established a relationship between low-CHO diets and eating behaviours; however, it is still unclear whether this relationship may positively or negatively affect health. Furthermore, there is little evidence to show whether body composition is associated with the eating behaviours of low-CHO diet users. Investigations are necessary to evaluate the eating behaviours of individuals following low-CHO diets to better understand the suitability and sustainability of low-CHO diets. This will enable the development of tailored initiatives and evidence-based dietary advice that promotes optimal health among individuals following a low-CHO diet.

Given the potential of low-CHO diets to positively influence body composition and improve eating behaviours, the present study aimed to explore the eating behaviours and body composition of free-living self-reported low-CHO diet users. The eating behaviours and body composition data analysed here were collected as part of a larger study to assess the nutritional status of free-living low-CHO diet users. The study results were part of previous theses (Knightbridge-Eager, 2020; Rassam, 2020).

1.3 Aim, Objectives, and Hypothesis:

This study aimed to investigate the differences in eating behaviours and body composition among different CHO categories of free-living, self-reported low-CHO diet users.

1.3.1 Objectives

The specific objectives of this study were to:

1. Assess the body compositions of low-CHO diet users overall and by level of CHO intake.
2. Assess the dietary intake of low-CHO diet users overall and by level of CHO intake.
3. Assess the eating behaviours (restraint, hunger and disinhibition and their various sub-factors) of low-CHO diet users overall and by level of CHO intake.
4. Explore the relationships between body composition, macronutrient intake, eating behaviour, and diet duration in low-CHO diet users.

1.3.2 Hypotheses

Based on the objectives of the study, we hypothesised the following:

1. Low-CHO diet users will have lower body fat and higher muscle mass as CHO intake decreases (Hu et al., 2016; Romano et al., 2019).
2. The intakes of CHO and fat, but not protein, will vary significantly among self-reported low-CHO diet users (Chawla et al., 2020; Naude et al., 2022).
3. Given objective 3, we hypothesise that the cohort of free-living, self-reported low-CHO diet users will:

    3.1 Have high restraint, and that restraint will increase with each lower CHO intake group.

    3.2 Have low disinhibition, and that disinhibition will increase with each lower CHO intake group.

    3.3 Have low hunger and, that hunger will increase with each lower CHO intake group (Anguah et al., 2019).
4. Given objective 4, we hypothesised that in free-living, self-reported low-CHO diet users:

    4.1 Restraint will increase as carbohydrate intake decreases.

    4.2 High restraint, low hunger and low disinhibition scores will be associated with more favourable body composition measures (i.e., lower body fat and higher muscle mass) (Bond et al., 2001; Bryant et al., 2019).

1.4 Thesis Structure

The thesis has been assembled into four chapters. **Chapter One** introduces the background and purpose of the study and includes the aim, objectives, hypotheses, and researcher's contributions. **Chapter Two** reviews the literature on low-CHO diets and their relation to eating behaviours and body composition. **Chapter Three** is the research manuscript, which includes the abstract, introduction, methods, results, and discussion of findings. Finally, **Chapter Four** concludes the research and states how the aim and objectives have been met and the study's strengths, limitations, and future research recommendations. The appendices include the recruitment poster, participant information sheet and consent form, food record, SOPs questionnaires and additional results.

1.5 Researcher Contributions

Table 1.1

Summary of Researcher's Contributions to the Study

Researchers	Contributions and Support
Prof Rozanne Kruger Supervisor	Academic supervisor who developed the study design. Advised about research direction and data analysis and assisted in dissemination. Revised and approved the thesis chapters and manuscript. Co-investigator of the LOCA study, obtaining funding, developed study design and methodology and oversaw data collection and analysis.
Prof Ajmol Ali Co-Supervisor	Academic mentorship, assistance with interpretation of results. Revised and approved the thesis chapters and manuscript.
Dr Marilize Ritcher Co-Supervisor	Assisted with statistical analysis and interpretation of results. Co-investigator of the LOCA study, obtaining funding, developed study design and methodology and oversaw data collection and analysis.

Chapter 2

Literature Review

2.1 The prevalence of dieting in New Zealand

The prevalence of dieting worldwide is significant, as people seek to lose weight or improve their health through dietary changes. A recent study found that 45% of adults globally were trying to lose weight, with 44% stating they would act by altering their diet or food intake (Bailey et al., 2021). In 2021, the global weight management market was valued at USD 132.7 billion and is expected to reach USD 298.7 billion by 2030. The Asia Pacific region accounted for more than 84% of revenue for this market in 2021 (Grand View Research, 2021). The market's growth is driven by rising obesity rates, increasing health consciousness, and various commercially available solutions, such as weight loss programmes and supplements (Grand View Research, 2021).

A significant proportion of the New Zealand (NZ) population has tried to lose weight or improve their health through dietary changes. In 2018, 53% of adults made such an attempt (Ministry of Health, 2019). A study on NZ adolescents found that 48% of females and 28% of males attempted to lose weight in 2020 (Lau, 2021). Many weight loss seekers have been observed opting for unhealthy and potentially dangerous strategies, including fasting, skipping meals, diet pills, laxatives, binge eating, vomiting, or smoking (Utter et al., 2012). Individuals who identified as female, Māori or Pacific ethnicity, or were overweight or obese were more prone to using such unhealthy weight loss techniques (Utter et al., 2012).

In the realm of popular diets, a wide array of approaches exists to altering eating habits. These diets vary regarding macronutrient manipulation, timing restrictions, or specific food group restrictions, including low-fat, low-carbohydrate, and high-protein diets, intermittent fasting, and various dietary restrictions such as gluten-free, vegetarian, plant-based, or Mediterranean diets (Freire, 2020). Additionally, some individuals may adopt strategies such as calorie counting, supplementation with commercial products, or meal replacements (Anton et al., 2017). Specific diets have become increasingly popular as the prevalence of obesity and awareness of its associated health implications rise (World Health Organization, 2021). However, it is important to note that the evidence supporting many of these popular diets is often limited and based on subjective opinions and personal accounts, often disseminated through social media and magazines. A review of popular diets revealed a lack of robust evidence to support their efficacy for sustained weight loss and long-term health benefits (Freire, 2020). No single diet emerged as superior, and some diets even show potential risks, including nutrient deficiencies, disordered eating patterns, and weight regain over time (Freire, 2020). Despite this, a significant proportion of individuals continue to attempt to achieve weight loss through popular, restrictive approaches.

One of the notably popular dietary trends is low-carbohydrate (low-CHO) diets. A large proportion of individuals globally (approximately 39%) turn to reducing CHO intake as a primary weight management strategy (Bailey et al., 2021). In 2017, the low-CHO diet was one of NZ's sixth most common dietary profiles, practiced by an estimated 5.4% of the country's population (Maclaren et al., 2017). In a NZ study, a low-CHO diet ranked as the fifth most favoured among female adolescents, with 13% adherence, while being the most popular choice for male adolescents, with 15% choosing it (Lau, 2021). Additionally, a low-CHO diet was identified as one of the most popular nutrition philosophies disseminated through online books and podcasts in NZ (Prendergast, 2016). The low-CHO diet appeals to many as it offers an alternative to traditional calorie-restricted diets and can potentially cause rapid initial weight loss (Oh et al., 2019).

Due to the widespread popularity of the low-CHO diet, it is essential to investigate its effects and potential implications for various aspects of health and well-being. Understanding the safety, efficacy, and associated benefits and risks of low-CHO diets, including their impact on weight loss, metabolic health, psychology, and long-term sustainability, is crucial. Healthcare professionals need this knowledge to provide evidence-based recommendations to individuals seeking dietary guidance. Furthermore, the findings from such research can inform the development of public health guidelines aimed at promoting optimal dietary choices at the population level. By exploring the impact of low-CHO diets on health, valuable insights can be gained into their potential role in disease prevention and management strategies. Further research is needed to comprehensively understand the long-term effects of low-CHO diets, highlighting the ongoing pursuit of knowledge in this field. Therefore, the aim of this narrative review is to discuss low-CHO diets, investigate eating behaviours, and explore the relationships between them and their relation to body composition. Search terms, including low-carbohydrate, diets, carbohydrate restriction, ketogenic, eating behaviour, restraint, hunger, disinhibition, body composition, and New Zealand, were used in EBSCOhost, Massey University Library, Nutrients, Cochrane Library and Google Scholar. Ministry of Health resources were also used. This narrative review prioritised the utilisation of the latest research and literature. Inclusion criteria required studies to involve adult or adolescent humans. While an effort was made to incorporate NZ-based studies, the limited research on this topic necessitated the inclusion of international studies.

2.2 The low-CHO diet

2.2.1 What is a low-CHO diet?

The origins of the low-CHO diet can be traced back to 1864 when an English patient named William Banting shared his weight loss success through a book entitled, "Letter on Corpulence, Addressed to the Public" (Banting, 1869). Banting's approach, known as "Banting's System", consisted of restricted CHO intake, particularly refined sugars and starches, believed to fatten the body, and emphasised the consumption of protein and fat (Banting, 1869). In the early 20th century, a similar dietary regimen emerged as a therapeutic strategy for managing epilepsy (Sampaio, 2016; Wilder, 1921). The concept of ketosis was introduced as physicians observed a reduced incidence of seizures after following a diet low in CHO and relatively high in fat and protein. This diet was appropriately termed the ketogenic diet and continues to be employed as a therapy for drug-resistant epilepsy (Sampaio, 2016; Wilder, 1921). It was not until the 1970s that Dr Robert Atkins sparked a renewed interest in low-CHO diets through his book "Dr Atkins' Diet Revolution" (Atkins, 1972). It promoted a reduced intake of CHO and increased consumption of fat and protein to induce a state of ketosis, primarily for weight loss. Over time, this diet has been adapted, re-named, and popularised through various books, mainstream media, and social media platforms, resulting in a multitude of diet variations designed for specific purposes, including weight loss, metabolic health, and general well-being, each with unique CHO restrictions and guidelines (Barber et al., 2021). The most popular low-CHO diets of today have been summarised in Table 2.1.

Table 2.1
Types of Low-Carbohydrate Diets

Diet	Reference	CHO restriction	Additional features and uses
Moderate-Low CHO Diet	Naude et al. (2022); Oh et al. (2019); Silverii et al. (2022)	<150 g/d Or 26 to 44% EI	Used for weight loss and maintenance. CHO is replaced with protein and fat.
Low CHO High Fat Diet (LCHF)	Noakes and Windt (2017); Oh et al. (2019); Zinn et al. (2018)	<130 g/d or 26% EI	Emphasises fat (>33% EI) for satiety.
Very-low CHO Diet	Cicero et al. (2015); Fields et al. (2016); Noakes and	<20-50 g/d or 5-10% EI	To achieve the state of ketosis for primarily weight loss and maintenance

Diet	Reference	CHO restriction	Additional features and uses
	Windt (2017); Oh et al. (2019)		
Classic Ketogenic Diet	Sampaio (2016); (Wilder, 1921)	2-10% EI or 20-50 g/d	Used for the treatment of epilepsy. The ketotic state is confirmed by urine or blood tests.
Atkins Diet	Atkins (1972); Fields et al. (2016)	Phase 1: 20 g/d, or 5% EI. Later phases: 80-100 g/d	CHO is replaced with fat and protein. 4 phases: 1. Induction: to induce ketosis and weight loss; 2. weight loss; 3. pre-maintenance; 4. maintenance
Paleo Diet	Cordain (2012); Fields et al. (2016)	Varies. ~25% EI	55-65% animal foods and 35-45% plant foods. Limits processed foods. ~33% protein, and 42% fat
The South Beach Diet	Agatston (2005); Fields et al. (2016)	Phase 1: 40-50 g/d Phases 2-3: ≤140 g/d	3 phases: 1: two weeks; 2: until desired weight loss is achieved; 3: maintenance. Restricts saturated fat
The Zone Diet	Fields et al. (2016); Sears and Lawren (1995)	100-150 g/d or 30-40% EI	Claims to reduce weight, inflammation, and ageing. Protein 30% EI, fat 30% EI

CHO: carbohydrate; %EI: percent of energy intake; g/d: grams per day; LCHF: Low Carbohydrate High Fat.

A balanced diet includes appropriate amounts of macronutrients, including CHO, fat, and protein. For the general NZ population, the recommended macronutrient distribution ranges for CHO, fat and protein are 45-65%, 20-35%, and 15-25% of daily energy intake (EI), respectively, as outlined by the National Health and Medical Research Council (2005). These guidelines aim to mitigate the risk of chronic diseases while ensuring sufficient intake of essential micronutrients. CHO, in particular, plays a crucial role in providing energy and vital micronutrients such as fibre, vitamins, and minerals to the body (Oh et al., 2019). In NZ, the average contribution of CHO to daily EI was approximately 46% for males and 47% for females, indicating that the population falls within the recommended range (Ministry of Health, 2011). However, a growing number of individuals globally and in NZ are seeking to further reduce their CHO intake by adopting low-CHO diets as a weight loss strategy. Modern low-CHO diets typically restrict CHO-rich foods such as grains, sugars, and starchy vegetables to below 20% of total daily EI, replacing the energy source through increased consumption of fats and protein to 55–65% and 25–30%, respectively (Barber et al., 2021). It is important to note that such macronutrient distributions may exceed or fall short of established recommendations, posing potential risks to nutrient status and overall health.

One of the notable challenges and downfalls of the low-CHO diet is the heterogeneity among definitions and the variations in macronutrient composition (Table 2.1). For example, the Classic Ketogenic diet recommends a very low intake of CHO, often below 50 g/day, to induce ketosis, while The Zone Diet allows for a higher CHO intake, around 100-150 g/day (Sampaio, 2016; Sears & Lawren, 1995). This lack of standardised definitions and guidelines makes it challenging to compare the results of studies that evaluate the effects of different low-CHO diets and draw definitive conclusions about their impact on various health outcomes.

For the present article, it is crucial to establish specific classifications of the low-CHO diets being investigated based on the level of CHO restriction or intake per day. Based on the above studies and classifications (Table 2.1, Table 2.2), it is fair to conclude that a low-CHO diet contains ≤150 g of CHO per day (Brouns, 2018; Westman et al., 2007), moderately low (ML) contains >100 and <150 g/day (Brouns, 2018), low contains (L) ≥50 and <100 g/day (Bilsborough & Crowe, 2003), and very-low (VL) contains <50 g/day (Brouns, 2018).

2.2.2 The low-CHO diet as a weight management approach

One of the key driving factors behind the high dieting prevalence is the increasing rate of obesity, recognised as a global epidemic (World Health Organization, 2021). Body mass index (BMI) is a measure of weight relative to height used to categorise individuals based on established criteria. For adults, average weight is a BMI of 18.5-24.9 kg/m^2, overweight is a BMI greater than or equal to 25 kg/m^2, and obesity is a BMI greater than or equal to 30 kg/m^2. An elevated BMI is strongly associated with an increased risk of some of the biggest causes of death worldwide, such as cardiovascular diseases (CVD), diabetes, musculoskeletal disorders and some cancers (World Health Organization, 2021). The most recent National Nutrition Survey in NZ found a mean BMI of 27.6 kg/m^2 for both male and female adults, and although dated, it is based on accurate data (Ministry of Health, 2011). More recent (self-reported) data from the 2020/2021 NZ Health Survey reports a mean adult BMI of 28.6 kg/m^2 and found that 33.7% of adults were overweight and 34.3% were obese (Ministry of Health, 2021). Obesity rates vary broadly between ethnicities, with 71.3% of Pacific, 50.8% of Māori, 31.9% of European/Other and 18.5% of Asian adults being classed as obese. This data shows an overall increasing weight trend, suggesting that average energy intake and expenditure are unbalanced across the nation, and a substantial proportion of individuals are at risk of noncommunicable diseases.

BMI is a widely used tool but is limited as it does not account for body composition. Body composition is the proportions of different components that make up the human body, specifically the relative amounts of fat, muscle, bone, and other tissues. Body composition varies significantly between individuals, depending on various factors, including genetics, environment, age, sex, and lifestyle choices. Body composition analysis can provide deeper insights into an individual's health status, fitness level, and risk factors for various health conditions. For example, excessive body fat percentage (BF%) is associated with an increased risk of obesity-related diseases such as type 2 diabetes (T2DM), CVD, and particular cancers (Holmes & Racette, 2021). Moreover, an appropriate amount of lean muscle mass is associated with better metabolic health and physical performance, and it can be used to monitor physical changes throughout a dietary intervention (Holmes & Racette, 2021).

Various methods are used to assess body composition, ranging from simple techniques such as skinfold measurements and bioelectrical impedance analysis (BIA) to more advanced methods like dual-energy X-ray absorptiometry (DXA) and air displacement plethysmography (Bod Pod). The two primary components of body composition are fat mass and fat-free mass. Fat mass refers to the amount of adipose tissue (body fat) in the body, while fat-free mass includes all other tissues, such as muscle, organs, bones, tendons, ligaments, and fluids. Body composition measures can provide more reliable and informative results than other measurements, such as body weight or BMI, and are not influenced by subjectivity, resulting in an improved understanding of an individual's body composition and overall health (Holmes & Racette, 2021).

The most common application of low-CHO diets is a dietary approach for promoting weight loss. Nonetheless, a review of the available relevant literature reveals conflicting and inconclusive evidence regarding the efficacy and safety of the diet. Table 2.2 presents a review of randomised control trials, observational studies, systematic reviews, and meta-analyses regarding use of low-CHO diets as a weight management approach. These investigations yield varying results, highlighting the complexity of this dietary approach.

Some studies have observed that, in comparison to a control diet consisting of moderate-CHO consumption, low-CHO diets can produce faster weight loss in the short term (≤six months) (Dyson et al., 2007; Naude et al., 2022; Silverii et al., 2022). However, in the long term (>six months), the evidence becomes less significant, and in some instances, no discernible differences from the control diet are observed (Dong et al., 2020; Dyson et al., 2010; Meckling et al., 2004; Oh et al., 2019; Volek et al., 2004) (Table 2.2). Some studies have further investigated the impact of low-CHO diets on body composition. Many have observed a reduction in visceral and total fat mass, as well as a decrease in BF% (Gram-Kampmann et al., 2022; Hu et al., 2022; Perissiou et al., 2020; Romano et al., 2019). Such changes are typically associated with a decreased disease risk and overall improved health (Perissiou et al., 2020). Given the generally high protein content of low-CHO diets, they are often regarded as effective in increasing muscle mass. However, controlled application of these diets has produced both desirable increases (Hu et al., 2016) and undesirable decreases (Gram-Kampmann et al., 2022; Perissiou et al., 2020) in muscle mass (Table 2.2). This discrepancy is likely due to variations in methods, intervention, dietary protein content and participants (body weight and composition, health status, and ethnicity). Moreover, adherence to low-CHO diets has shown a range of significant health benefits, such as improved glycaemic control (Gram-Kampmann et al., 2022), improved blood lipid profiles (Sanada et al., 2018), decreased blood pressure (BP) (Unwin et al., 2019), improvements in psychological health (Kakoschke et al., 2021), and reduced CVD risk (Hu et al., 2022). On the contrary, some systematic reviews have observed an increased risk of adverse lipid profile effects and increased BP levels resulting from low-CHO diets compared to control diets (Chawla et al., 2020; Dinu et al., 2020).

Despite the significant results in some studies, their limitations attenuate their validity, such as small sample sizes, short study durations, poor dietary adherence, uncontrolled variables, potential biases, and use of self-reported data. There is also a disproportionate focus on certain types of low-CHO diets, where some are backed by a significantly larger number of supporting studies than others, skewing the findings of systematic reviews and meta-analyses (Anton et al., 2017). The lack of rigorous testing, unstandardised definitions and methods, and the varied evidence base collectively pose a challenge when ascertaining the optimal level of CHO restriction that produces the best outcomes on weight, body composition, and overall health. The current limitations and conflicting nature of research on this topic subsequently call for further investigation.

Table 2.2

Studies Investigating the Effects of Low-CHO Diets as a Weight Management Approach

Reference	Population (age, group, place)	Aim (intervention diet CHO/ protein/fat intake)	Main outcomes	Strengths	Limitations
Randomised Controlled Trial					
Ebbeling et al. (2018)	• n=164 adults; 18-65 years; BMI of > 25 kg/m^2. • US	To determine the effects of diets varying in CHO to fat ratio on total EE. CHO: High, 60%, n=54; Moderate, 40%, n=53; or Low, 20%, n=57). Duration: 20 weeks	Total EE differed by diet with a linear trend of 52 kcal/d for every 10% decrease in the contribution of CHO to total EI. Lowering dietary CHO showed increased energy expenditure during weight loss maintenance.	Test diets were controlled for macronutrients and energy-adjusted to maintain weight loss.	Potential measurement error (doubly labelled water method), non-compliance, and low generalisability.
Gram-Kampmann et al. (2022)	• n=71 adults; >18 years; with T2DM • Denmark	To investigate the efficacy and safety of a non-calorie–restricted low-CHO diet on glycaemic control, body composition, and CVD risk factors in patients with T2DM. Low-CHO: 20% EI (n=49) Control: 50-60% EI (n=22) Duration: 6 months	Compared to the control, the low-CHO diet reduced HbA1c, weight (−3.9 ± 1.0 kg), BMI (−1.4 ± 0.4 kg/m^2), WC (−4.9 ± 1.3 cm), total fat mass (−2.2 ± 1.0 kg; $p = 0.027$) and lean mass (−1.3 ± 0.6 kg; $p = 0.017$). No changes in blood lipids or BP.	Randomised design, well-matched study groups. Examined the isolated effect of a low-CHO diet. Adjusted for differences in medication, sex, age, diabetes duration, and smoking.	The open-label approach, self-reported glucose measurements and symptoms of hypoglycaemia. Lack of strict control of changes in physical activity, medication, EI, and diet macronutrient composition.
Hu et al. (2016)	• n=148 adults with obesity; 22–75 years • New Orleans, US	To examine the effects of a low-CHO diet and a low-fat diet (<30% fat) on weight and CVD risk factors and compare overall adherence between the two interventions.	Observed better adherence to a low-CHO diet, 2.2 kg or 2.3% greater weight loss, 1.1 greater reduction in % fat mass and 1.3 greater increase in % lean mass than the low-fat diet.	A high completion rate, long duration, relatively large, diverse population, and multiple	Majority of subjects (89%) were women. Adherence was based on self-reported 24-hour dietary recalls which may

Reference	Population (age, group, place)	Aim (intervention diet CHO/ protein/fat intake)	Main outcomes	Strengths	Limitations
		CHO: <40 g/d Duration: 12 months		indicators of adherence.	not represent the usual diet of the participant.
Kakoschke et al. (2021)	• n=61 adults with obesity and T2DM • Australia	To explore the effects of a low-CHO diet on mood and cognitive function and explore the potential predictors of changes in psychological health. CHO: 14%, Protein: 28% Fat: 58% Duration: 2 years	Weight loss was 9.1% after 12 months and 6.7% after 2 years with no difference between low-CHO and high-CHO diet groups. Over time, improvements in total mood occurred.	Comprehensive psychological health assessments and cognitive tests. Intense intervention delivery, high dietary compliance. Isocaloric control diet.	Limited applicability to individuals with T2DM. The sample was predominantly Caucasian. Some participants were taking anti-depressant medication. No post-intervention follow-up.
Perissiou et al. (2020)	• n=64 obese adults; 18-50 years. • Australia	To assess the effect of low-CHO diet in combination with supervised exercise on cardiorespiratory fitness, body composition and cardiometabolic risk factors in obese individuals. CHO: <50 g/d. Duration: 8 weeks	Greater improvements in $\dot{V}O_2$peak and fat mass index compared to the control. A ketogenic state was associated with greater reductions in total body fat, visceral adipose tissue, fat mass index and C-reactive protein but also with greater reductions in lean muscle mass.	The experimental group provided pre-prepared meals and snacks to control intake.	Unblinded due to the trial design. The control group were not provided pre-prepared meals. The portion-controlled meals may have helped weight loss.
		Observational / Cross-sectional			
Romano et al. (2019)	• 20 adults; mean 56 years; BMI 18-45kg/m^2; with T2DM. • Italy	To explore the effects of a VLCKD with synthetic amino acid protein supplementation on body composition and resting energy expenditure in the short-term reversal of T2DM. CHO: 5-10%EI (<25 g/d) Protein: 60-70%EI Fat: 25-30%EI	Weight loss was −11.07% at 4 weeks and −15.77% at 8 weeks. The saving of lean mass, reduction of fat mass (−17.75%), truncal fat (−20.72%), and abdominal fat (−24.80%), restored metabolic flexibility, the maintenance of resting energy expenditure, and the reversion of diabetes was observed.	100% recorded compliance.	Small sample size, lack of follow-ups, and the absence of a control arm.

Reference	Population (age, group, place)	Aim (intervention diet CHO/ protein/fat intake)	Main outcomes	Strengths	Limitations
		Duration: 8 weeks			
Sanada et al. (2018)	• n=200 adults with T2DM • Japan	To evaluate the long-term efficacy and safety of a non-calorie-restricted, moderately low-CHO diet on glycaemic and lipid profile control in patients with T2DM. CHO: 70–130 g/d or 30% Fat: 45% Protein: 20% Duration: 36 months	The intervention showed sustained effectiveness (without safety concerns) in improving HbA1c, lipid profile, and liver enzymes. Participants with a baseline BMI < 25 showed sustained body weight, and those with BMI ≥ 25 showed a decrease in body weight.	Large sample size, long duration.	43 participants were lost to follow-up. Observational study, so no control group. Bias and confounding factors cannot be ruled out.
Unwin et al. (2019)	• n=154 adults; 18+ years with T2DM or impaired glucose tolerance • England	To examine the impact of dietary CHO restriction on BP, weight, lipid profiles and antihypertensive drug prescribing. Duration: 24 months	Significant reductions in BP and mean weight reduction of 9.5 kg with marked improvement in lipid profiles. This occurred despite a 20% reduction in anti-hypertensive medications.	Long intervention duration.	Low internal validity as there were many variables not controlled. Subjects were not randomly generated. Minimal assessment of adherence to the diet.
Systematic Review / Meta-Analysis					
Chawla et al. (2020)	• 38 studies; 6499 adults	To compare the effects of low-CHO and low-fat diets on body weight, LDL, HDL, total cholesterol, and TG. Low-CHO diet: ≤40% EI from CHO Low-fat diets: ≤30% EI from fat Duration: 6–12 months	Low-CHO diets are effective at improving weight loss, HDL, and TG lipid profiles, although, with potential consequences of raised LDL and total cholesterol in the long term.	All studies were RCTs. Large sample size. Assessment of publication bias. Strict definitions of diets prevented bias from subjective classification.	Search limited to English publications. Only two studies analysed effects beyond 12 months. Most trials did not provide food, which lowered diet adherence. Varied physical activity engagement.

Reference	Population (age, group, place)	Aim (intervention diet CHO/ protein/fat intake)	Main outcomes	Strengths	Limitations
Churuangsuk et al. (2018)	• 12 systematic reviews; 10 with meta-analyses	To evaluate the weight loss outcomes reported in meta-analyses, regarding the quality of published systematic reviews. CHO: <60 g/d or <45% EI	Published systematic reviews have a substantial variation in their methods, including the definition of a low-CHO diet. Low-quality meta-analyses showed low-CHO diet superiority for weight loss (0.7–4.0 kg), while high-quality meta-analyses reported little or no difference between diets.	Addresses concordance and discordance in the results of published systematic reviews and meta-analyses.	Searched from 2000 to 2017. Limited to English. Most of the systematic reviews could be flawed and have confounding variables.
Dinu et al. (2020)	• 80 articles; 495 meta-analyses including a range of popular diets	To summarize and critically evaluate the effects of different diets on anthropometric parameters and cardiometabolic risk factors. CHO: ≤26% to ≤45%	A significant reduction in body weight was observed, especially in the short term (6 months) and with more extreme CHO restriction. As the follow-up period or the amount of CHO increased, the effect was reduced. The Mediterranean diet had the strongest and most consistent evidence, with no detrimental effects. Low-CHO diet showed beneficial effects on weight loss, but also risks of unfavourable lipid, glycaemic, or BP parameters.	A unique umbrella review. Large sample size.	Differing low-CHO diets, populations, methods, intervention durations, study quality and control diets. A limited number of clinical trials were available for many diets evaluated. An umbrella review does not account for potential omissions or overlapping of studies.
Dong et al. (2020)	• 12 studies; 1640 adults; 31-65 years. • US, Australia, UK, Israel, and China.	This meta-analysis aimed to assess the relationship between low-CHO diets and CVD risk factors. CHO: 40% Control: 45% to 55% Duration: 6 months to >1 year	Body weight decreased significantly compared with the control group (1.58 kg). <6 months had a weight change of -1.14kg and 6–11 months had a weight change of -1.73kg. A low-CHO diet for >1 year had no significant difference in weight from the control group.	RCTs included in this study were mostly high quality.	Potential confounding factors i.e., different dietary habits and preferences. Risk of selection bias. Varied CHO limits lead to clinical heterogeneity. Short study durations. Possible poor compliance by the subjects.

Reference	Population (age, group, place)	Aim (intervention diet CHO/ protein/fat intake)	Main outcomes	Strengths	Limitations
Naude et al. (2022)	• 61 RCTs; 6925 adults; >18 years; overweight or obese without or with T2DM, and without or with CVD risk. High-income countries.	To compare the effects of low-CHO diets with balanced-CHO diets, in relation to changes in weight and CVD risk, in overweight and obese adults without and with T2DM. Low-CHO: <50 g-150 g/d or < 45% Fat: 20-35% Protein > 20% Very low-CHO: ≤ 50 g/d or < 10% Duration: >2 weeks	Low-CHO and balanced-CHO diets had little to no difference in change in body weight, HbA1c, BP, and LDL cholesterol over three months to two years. Participant reported adverse effects: lack of appetite, bad breath, weakness, headaches, gastrointestinal problems, and psychosocial problems.	A comprehensive search strategy with no language restrictions.	Weight reduction trials were constrained by small samples, a lack of blinding, and a large loss to follow-up. The review may be affected by non-reporting bias. Evidence on participant-reported adverse effects was limited.
Silverii et al. (2022)	• 25 RCTs • Subjects with a BMI >30 kg/m^2	To assess whether low-CHO diets are associated with differences in weight loss and well-being in people with obesity, and their cardiovascular safety. CHO Control: 45%-60% Mild low-CHO: 26%-45% Very low-CHO: <26% or < 130 g/d Duration: 3-30 months	Low-CHO diets showed significant weight reduction at 3-4 (−2.59kg) and 6-8 months (−2.64kg), but no difference in the longer-term. Significantly greater BMI reduction only at 3-4 months (−1.66kg/m^2). Total or LDL cholesterol or BP were not affected, whereas a long-term reduction of TG (23.26 mg/dl at 18-30 months) and increase of HDL cholesterol (MD 4.94 mg/dl at 18-30 months), were observed.	Clear definition of the target population for the dietary intervention (i.e. obese subjects only) increases the reliability of results.	Varied definitions and restrictions of low-CHO diets. Most trials are small with short follow-ups. Results are mostly limited to United States contexts. Many trials show methodological limitations.

N: sample size, BMI: body mass index, kg: kilogram, CHO: carbohydrate, EE: energy expenditure, kcal/d: kilocalories per day, EI: energy intake, T2DM: type 2 diabetes mellitus, WC: waist circumference, BP: blood pressure, VLCKD: very low carbohydrate ketogenic diet, LDL: low-density lipoprotein, HDL: high-density lipoprotein, TG: triglycerides, RCT: randomised controlled trial, CVD: cardiovascular disease, MD: mean difference. Normal BMI < 24.99 kg/m^2. Overweight BMI 25-29.99 kg/m^2 Obese BMI ≥ 30.00 kg/m^2

2.2.3 Mechanisms of low-CHO diets

When investigating the effectiveness of popular diets to achieve weight loss, it is necessary to discuss the mechanisms through which these diets produce such outcomes. Certain proponents of low-CHO diets claim that limiting CHO consumption alters the body's metabolic processes, driving weight loss. One such metabolic process that has gained attention is the CHO-insulin model, which proposes that low-CHO intake reduces the secretion of insulin, a hormone involved in regulating blood glucose levels (Ludwig & Ebbeling, 2018). Lower insulin levels are theorised to promote more significant mobilisation and utilisation of stored body fat (Ebbeling et al., 2018). Another mechanism relates to the aforementioned ketogenic diet, which was developed as a treatment for epilepsy; however, it has become a popular weight-loss strategy due to its metabolic effects (Mohorko et al., 2019). The ketogenic diet severely restricts CHO intake, mimicking the fasting metabolism and creating the state of ketosis. In ketosis, the body shifts from using glucose as its primary fuel source to utilising ketones, produced from the liver's breakdown of fats. This can lead to significant weight loss, particularly in the form of body fat (Oh et al., 2019). Ketogenic diets are not advised for those with kidney failure, type 1 or type 2 diabetes, CVD risk, or breast-feeding or pregnant women due to various consequences of the diet, such as the high fat intake and the possibility of hypoglycaemia (Alharbi & Al-Sowayan, 2020). These interactions between macronutrients, hormones, and energy metabolism are still a subject of scientific debate, and further research is needed to fully understand their complexities (Ebbeling et al., 2018).

Other proposed mechanisms behind the efficacy of low-CHO diets are based upon the notion that restricting specific macronutrients results in a decrease in overall calorie consumption, thereby making calorie restriction the primary catalyst for weight loss. One such hypothesis relates to how dietary protein creates and prolongs the sensation of satiety to a greater level than CHO. Therefore, a diet low in CHO and high in protein is more effective at suppressing hunger and overall food intake, resulting in a caloric deficit and, ultimately, weight loss (Oh et al., 2019; Tremblay & Bellisle, 2015). This is supported by a systematic review that found that only low-CHO diets that created a decreased caloric intake produced significant weight loss (Bravata et al., 2003). While it is evident that calorie restriction leads to short-term weight loss, an increasing body of research supports using low-CHO approaches to maintain a healthy weight through various mechanisms (Noakes & Windt, 2017).

2.2.3 Potential adversities of a low-CHO diet

A low-CHO diet presents several areas of concern, including health, financial, social, and adherence considerations. One potential health concern associated with low-CHO diets is the risk of micronutrient deficiencies resulting from the restricted intake of CHO-based foods rich in essential vitamins and minerals (Schutz et al., 2021). Individuals following a low-CHO diet, especially those with very low-CHO intake, may be at an increased risk of micronutrient deficiencies including but not limited to fibre, folate, polyunsaturated fatty acids, and an array of vitamins and minerals (Paoli et al., 2012). One review documented a significant 10 to 70% reduction (from baseline) in intake of thiamine, folate, magnesium, calcium, iron, and iodine after adherence to a low-CHO diet (Churuangsuk et al., 2019). These deficiencies can have clinical consequences and may increase the risk of developing chronic diseases over the long term, including constipation, compromised bone health, renal calculi and growth failure (Bilsborough & Crowe, 2003; Sampaio, 2016).

Furthermore, an extended duration of relatively high intakes of fat and protein due to a low-CHO diet can trigger micronutrient imbalances, which can have adverse health effects. For instance, high intakes of fat may lead to the onset of dyslipidaemia (Sampaio, 2016), while excessive protein consumption has been demonstrated to cause a decreased glomerular filtration rate, particularly noted in individuals with mild renal impairment (Knight et al., 2003). A meta-analysis observed that low-CHO diets higher in animal-derived protein and fat sources, such as beef, pork, and chicken, correlated with increased mortality, while diets featuring higher intakes of plant-derived protein and fat sources such as vegetables and whole-grains were associated with lower mortality (Seidelmann et al., 2018). This indicates that the source of macronutrients may influence health and mortality more than the proportion of macronutrients. The depleted glycogen stores generated by low-CHO intake can pose a risk of hypoglycaemia, which is particularly concerning for individuals with type 1 or type 2 diabetes (Schutz et al., 2021; Turton et al., 2018). This means such individuals would need to closely monitor their blood sugar and medication levels appropriately, as low-CHO diets can reduce the need for insulin.

Another aspect to consider when evaluating the implications of adhering to a low-CHO diet is the potential economic impact. Compared to a typical moderate to high-CHO diet, low-CHO diets necessitate a higher consumption of protein, fats, and potentially certain speciality foods, including supplements, to achieve nutritional adequacy (Barber et al., 2021). This can result in escalated grocery expenses and the potential imposition of financial strain on individuals and households. Research indicates that as the proportion of CHO in a diet decreases, food costs significantly rise (Raffensperger, 2008). Raffensperger (2008) found that the most economical low-CHO diet was three times the cost of the most economical non-CHO restricted diet (where both diets met complete nutritional requirements). This highlights that the financial implications of a low-CHO diet may affect its long-term sustainability.

Following a low-CHO diet can instigate adverse social and emotional consequences that impact individuals' interactions, relationships, and overall well-being (Barber et al., 2021; Burns et al., 2001). The restrictive nature of such diets, often involving reducing or eliminating common foods, can introduce challenges in social settings and lead to feelings of isolation, exclusion, or the sense of being judged or criticised. Individuals may find it challenging to engage in social gatherings or dine out with friends and family, which may cause frustration or the sense of missing out on valued experiences (Hislop et al., 2006). Research has found that dieting individuals are at risk of facing social negotiations, pressures, increased stress levels, identity-related challenges, and even depression (French & Jeffery, 1994; Wadden & Stunkard, 1987). One study revealed that frequent dieters had a lower quality of life, particularly regarding emotional well-being and mental health (Burns et al., 2001). This highlights the complex social and emotional dynamics that result from deviating from conventional dietary norms.

Adherence to a low-CHO diet can be challenging for many individuals, particularly over prolonged durations, due to its restrictive nature and influence on dietary patterns (Johnston et al., 2014). One study that examined adherence to different dietary approaches found that low-CHO diets were associated with higher dropout rates than other dietary interventions (Hu et al., 2016). The challenges with diet adherence may be related to cultural, religious, or economic barriers and personal preferences (Kumar et al., 2022). Additionally, limited CHO intake may lead to cravings, previously identified as a primary catalyst of non-adherence (Hall & Most, 2005). According to Johnston et al. (2014), the success and sustainability of a dietary regime are more dependent on the individual’s tolerance and adherence rather than the macronutrient composition of the diet.

2.3 Eating Behaviours

2.3.1 Why understanding eating behaviours is important

Eating behaviour is “a broad term encompassing food choice and motives, feeding practices, dieting, and eating-related problems such as obesity, eating disorders, and feeding disorders” (LaCaille, 2020). These behaviours significantly influence dietary choices, weight management, and overall health (Herman & Polivy, 1975; Johnson et al., 2012; LaCaille, 2020). Behaviours such as portion size selection, frequency of eating, food preferences, and responses to hunger and fullness cues can influence energy balance, which is the fundamental determinant of weight gain or loss (Anton et al., 2017). By understanding these behaviours, individuals and health professionals can make informed food choices and develop effective strategies to support healthy weight management. Moreover, comprehending eating behaviour factors such as food preferences, emotional eating, and dietary restraint can assist in the development of personalised nutrition plans, improve psychological relationships with food, mitigate the risk of nutrient deficiencies, and reduce the risk of diet-related diseases (Herman & Polivy, 1975; Leblanc et al., 2012). Understanding the complex interplay and effects of eating behaviours is imperative in the current context of rapidly rising obesity rates (Ministry of Health, 2021) and the high prevalence of dieting practices, many of which show inconclusive efficacy in the research (Anton et al., 2017; Freire, 2020). Stunkard and Messick (1985) explored the complex interactions between biological, psychological, and environmental factors that influence relationships with food. Their work led to the classification of eating behaviours into three core factors: restraint, disinhibition, and hunger. Decades later, through additional psychometric evaluation, Bond et al. (2001) further delineated sub-factors within these three factors, offering a more comprehensive explanation of these behaviours. These factors and subfactors are presented in Table 2.4, with further elaboration provided in subsequent sections.

Table 2.3

A Summary of the Factors and Sub-Factors of Eating Behaviours from the Three Factor Eating Questionnaire (Bond et al., 2001)

Factor	Sub-Factor	Definition
Restraint	Flexible	The ability to regulate food intake by making conscious and flexible choices about eating, considering hunger and satiety cues, and balancing food enjoyment and health goals.
	Rigid	The tendency to restrict food intake based on strict rules or external regulations, often leads to a heightened focus on forbidden foods and an increased risk of overeating or disinhibited eating.
Disinhibition	Habitual	The tendency to eat impulsively or overeat in response to habitual cues or routines, such as eating when watching TV or snacking out of habit.
	Emotional	The tendency to eat in response to emotional triggers, such as stress, boredom, or sadness.
	Situational	The tendency to eat in response to specific environmental or social cues, such as social events, food advertisements, or availability of food.
Hunger	Internal	The physiological sensation of hunger that arises from internal cues, such as an empty stomach or low blood sugar levels.

	External	The desire to eat triggered by external cues, such as the sight or smell of food, even in the absence of physiological hunger.

2.3.2 How eating behaviours are measured

The Three-Factor Eating Questionnaire (TFEQ) serves as a widely used tool in research and clinical settings that measures the three factors of human eating behaviours concerning weight and food intake: restraint (comprising 21 items), disinhibition (comprising 16 items), and hunger (comprising 14 items), (Bond et al., 2001). The TFEQ questionnaire was initially developed in the mid-1980s by Stunkard and Messick (1985) and later adapted to include Bond's sub-factors, and has since been standardised and validated (Bond et al., 2001). The questionnaire requires individuals to self-report their agreement or frequency of various statements or experiences using a Likert-type scale. The resulting data can help researchers and clinicians understand individuals' eating patterns and psychological factors related to food intake (Papini et al., 2022). As such, individuals with high responses to factor 1 (restraint) may benefit the most from guidance on achieving a balance of calories, nutrition information, and conventional techniques for regulating behaviours for stimulus control. High scorers for factor 2 (disinhibition) may find greater success in behavioural management and from seeking interpersonal assistance through group-oriented approaches, particularly in addressing emotional triggers such as anxiety, depression, or loneliness (Herman & Polivy, 1975). Finally, those who score high on factor 3 (hunger) may better manage their hunger by utilising attributional techniques or through extended use of medication that suppresses appetite (Stunkard & Messick, 1985).

2.3.3 The three factors of eating behaviour

Restraint

Restraint involves an individual's conscious effort to manage their weight and cognitively control their food intake through strategies such as consuming small portions, avoiding high-calorie foods, and stopping eating before feeling completely full (Stunkard & Messick, 1985). The concept of dietary restraint originated from studies investigating the effects of purposeful limitation of food intake on weight management and eating behaviours. In the 1970s, Herman and Polivy (1975) introduced the Restraint Scale to assess individuals' tendency to restrict food intake for weight control. Initially, dietary restraint was perceived as a positive quality for managing weight; however, further research has demonstrated that prolonged or extreme restraint could have detrimental outcomes, including increased risk of disordered eating behaviours (Herman & Polivy, 1975).

Contemporary research has made the important distinction between dieting and restrained eating (Mills et al., 2021). While dieters and restrained eaters may engage in some level of intentional food restriction, the key difference is their underlying motivations and attitudes towards eating. Dieters primarily focus on achieving weight-related goals for health-related or aesthetic reasons through various strategies, such as reducing calorie intake or following specific dietary plans or programmes. Restrained eaters have a more self-imposed and consistent tendency to control their food intake by setting strict rules around eating to maintain a particular body shape or prevent weight gain, sometimes even without weight loss goals (Mills et al., 2021).

Restraint has been refined into two sub-factors: rigid and flexible control (Westenhoefer et al., 1999). Rigid control is an all-or-nothing approach to eating and weight management where foods perceived as "bad" or unhealthy are entirely avoided. Individuals practising rigid control firmly adhere to dietary rules and regulations, often setting strict limits on calorie intake, food choices, or meal timing, which involves high self-control (Westenhoefer et al., 1999). The strict rules and deprivation associated with rigid control can be psychologically burdensome over time. They may increase the likelihood of intense food cravings, feelings of guilt or shame when deviating from rules, a negative relationship with food and ultimately, disinhibited eating or binge eating episodes (Johnson et al., 2012).

Flexible control involves a more adaptable and balanced approach to eating and weight management as practising individuals allow themselves flexibility and freedom in food choices while maintaining an overall healthy and balanced eating pattern. Foods perceived as unhealthy may be consumed in limited quantities without subsequent feelings of guilt. Internal cues of hunger and satiety are used to make mindful choices based on nutritional needs and personal preferences (Westenhoefer et al., 1999). Flexible control has been associated with more favourable outcomes, including a healthier relationship with food, reduced risk of disordered eating patterns, and long-term adherence to a balanced diet (Johnson et al., 2012).

Disinhibition

Disinhibition refers to a loss of cognitive control or restraint resulting in the tendency to overeat and give in to food temptations. This commonly occurs in obesogenic environments that encourage overconsumption (Lake & Townshend, 2006). Disinhibition can include eating in response to negative emotions, being unable to resist tempting food stimuli or cues, and overeating due to the enjoyable taste of food (Stunkard &

Messick, 1985). Disinhibition has been divided into three constructs: habitual susceptibility, emotional susceptibility, and situational susceptibility (Bond et al., 2001).

Habitual susceptibility represents a tendency to lose control with eating in certain habitual or routine circumstances. This can occur when individuals are in an environment or situation strongly associated with food cues or triggers, for instance, an individual who has developed a habit of indulging in a bowl of ice cream every night while watching television. Whether they are truly hungry or not, watching TV triggers a habitual response to crave and consume ice cream. The habitual response is a learned behaviour that overrides typical eating cues, resulting in overeating or the consumption of high-calorie foods that may not align with nutritional goals (Bond et al., 2001).

Emotional susceptibility refers to the vulnerability to disinhibited eating behaviours in response to emotional states (Bond et al., 2001). Many individuals turn to food as a coping mechanism or source of comfort during stress, sadness, boredom, or other emotional states. In such circumstances, food is used to regulate emotions rather than as a response to physiological hunger cues, which can lead to episodes of overeating or binge eating to seek emotional relief or distraction (Macht & Simons, 2011).

Lastly, situation susceptibility is disinhibition influenced by specific environmental cues or social contexts such as social gatherings, special occasions, and buffet-style meals. Individuals susceptible to situational disinhibition are more likely to lose control with eating due to the availability of foods, social pressure, or the perception that it is a special occasion, leading to a mindset of "indulging" or disregarding usual dietary restrictions (Bond et al., 2001).

Hunger

Hunger relates to an individual's perception of their physiological symptoms of hunger and how this perception drives their food intake. This can include intense feelings of hunger that lead to overconsumption, a lack of satiety, or unpleasant sensations in the stomach (Stunkard & Messick, 1985). Susceptibility to hunger has been positively correlated with energy intake (Leblanc et al., 2012). Two hunger factors have been established, including internal and external hunger, which describe whether hunger is perceived and regulated by internal or external cues (Bond et al., 2001).

Internally perceived cues involve sensations within the body, such as physiological signals related to energy balance and nutrient needs, i.e., stomach contractions, blood sugar levels, stomach emptiness or fullness.

This type of hunger regulation uses internal physiological cues and the body's biological need for nourishment to guide eating behaviour. In contrast, external cues occur outside the body, which involve social or environmental triggers and learned associations of hunger and eating behaviour, i.e., the sight or smell of food, food advertisements, time of day, and social eating norms. Such cues can stimulate appetite and create a desire to eat, regardless of the individual's actual physiological need for food (Bond et al., 2001). Increased susceptibility to external hunger is more highly correlated with weight gain and BMI than internal hunger in specific populations (Hays & Roberts, 2008).

2.3.4 Eating behaviour and weight management

A substantial body of research investigates the intricate relationship between eating behaviours, weight status and body composition. Table 2.4 provides an overview of the relevant literature that evaluates this relationship and utilises the TFEQ to assess eating behaviours. This research aims to discern the levels or scores of each TFEQ factor and sub-factor that may exert positive or negative influences on anthropometric parameters and, ultimately, health. Evidence suggests that higher levels of disinhibited eating behaviours, including both habitual and emotional disinhibition, are associated with elevated BMI (Blumfield et al., 2018; Shiozawa et al., 2020), increased BF% (Hootman et al., 2018; Pacheco et al., 2021; Shepherd, 2018), obesity, hedonically driven food choices, worsened diet quality and quicker eating speeds (Bryant et al., 2019; Shiozawa et al., 2020). The associations with disinhibition may be attributed to impulsivity in consuming palatable foods (Bryant et al., 2019). Hunger has been associated with increased BMI, weight, energy intake, propensity for individuals to overeat, and diabetes diagnoses (Bryant et al., 2019; Hootman et al., 2018; Jacob et al., 2023). Research findings concerning restraint and weight management have been mixed and it remains unclear whether high levels of restraint are beneficial or detrimental to health (Bryant et al., 2019). Restraint has predicted significant weight loss (Papini et al., 2022), however, it has been positively associated with BF% and BMI (Hoenink et al., 2023; Pacheco et al., 2021; Shepherd, 2018; Shiozawa et al., 2020). The observed adverse effects of restraint include its correlation with elevated BMI scores, BF%, and central obesity, as well as poorer diet quality, overeating, and the potential for a fourfold increase in the risk of obesity (Bryant et al., 2019; Pacheco et al., 2021). Contrastingly, positive effects of restraint have been observed, including its association with lower dietary intakes, improved body fat profiles, healthier body weight, improved weight regulation, reduced cravings, improved appetite, and a healthy dietary profile (Bryant et al., 2019; Shepherd, 2018). This conflict may partly be explained by the sub-factors of restraint, including the degree of rigidity or flexibility in an individual's behaviours and the interaction with other factors (Bryant et al., 2019). In many instances, rigid restraint is associated with higher scores of disinhibition, BMI, and disordered eating, while contrastingly, flexible restraint is linked to lower scores of disinhibition, BMI, EI, and more successful weight management (Timko & Perone, 2005; Westenhoefer et al., 1999). Additionally, individuals more vulnerable to emotional disinhibition have been associated with increased takeaway food consumption and BF% (Hoenink et al., 2023). It is crucial to note that healthy BMI or body composition measures do not inherently indicate optimal eating behaviours or vice versa (Shepherd, 2018). For instance, a cross-sectional study found that individuals with high restraint demonstrated less fast-food consumption than those with lower restraint; paradoxically, however, they also exhibited higher BF% on average (Hoenink et al., 2023).

Several studies have focused on the intricate relationships between anthropometry and eating behaviours, revealing variations across different populations or demographics. Notably, regardless of their weight, women tend to cognitively control their eating behaviour and experience more feelings of disinhibition and hunger to a greater degree than men (Ernst et al., 2015). Shiozawa et al. (2020) observed a significant positive correlation between restraint and BMI exclusively in females and between hunger and BMI only in males. These studies imply that men and women may vary in their susceptibility to certain eating behaviours and that these behaviours may influence weight differently between genders. The underlying reasons behind these discrepancies remain unclear; however, they are likely related to the higher prevalence of dieting and eating disorders observed in women in comparison to men (Lau, 2021; Utter et al., 2012). Furthermore, differences in eating behaviours among ethnicities likely exist, which may contribute to the weight variations observed between ethnic groups (Shepherd, 2018). A NZ study revealed that Pacific women were significantly more prone to displaying behaviours supporting weight gain, including high hunger, external hunger, disinhibition, and habitual disinhibition, than NZ-European women (Shepherd, 2018). Conversely, restraint, a behaviour associated with healthy weight management, was higher for NZ-European women than Pacific women (Shepherd, 2018). These findings align with the higher NZ obesity rates observed in the Pacific ethnic group compared to the NZ-European group (Ministry of Health, 2021).

Research on the relationship between eating behaviours and anthropometry has limitations that diminish findings. These limitations include reliance on self-reported data, dated data, limited generalisability to broader populations, potential biases, and confounding variables. Additionally, not all studies in this review consistently include the same TFEQ factors and sub-factors, making conclusions difficult to determine. Most of the recent studies are cross-sectional, with only a single accessible randomised control trial identified. There is a clear need for further research to provide a more comprehensive understanding of how eating behaviours and anthropometry relate.

Table 2.4

Summary of the Current Research on Eating Behaviours and Body Composition

Reference	Population (age, group, place)	Aim	Main outcomes	Strengths	Limitations
			Randomised Controlled Trial		
Papini et al. (2022)	• n=287 adults; 18 to 65 years with overweight or obesity • Kansas, US	To examine changes in TFEQ scores on successful weight loss and weight maintenance. Duration: 6-18 months	Restraint at baseline was the only significant predictor of 5% weight loss at 6 months. None of the TFEQ subscale scores at 6 months predicted weight maintenance at 18 months.	Large sample size, equal sex ratio, good follow-up duration. Investigation of the predictive utility of the TFEQ.	Lacked inclusion of other important health outcome variables, such as health-related quality of life.
			Observational / Cross-sectional		
Blumfield et al. (2018)	• n=602 adults; 18–69 years • New York, US	To examine if eating behaviours mediate the relationship between sleep and BMI.	Poorer sleep quality was associated with greater hunger and disinhibition. Higher disinhibition was associated with higher BMI. Disinhibition mediated the relationship between sleep quality and weight status in both males and females.	Large study sample of free-living adults. Data is strengthened using validated and easily replicated survey tools.	Self-reported data to measure eating behaviour. Use of the original TFEQ which assesses disinhibition as a single construct. Causality cannot be inferred because of its cross-sectional study design.
Hoenink et al. (2023)	• n=4791 adults, mean age of 51y • UK	To investigate the moderating role of eating behaviour traits in the association	Emotional and uncontrolled eating were positively associated with takeaway consumption and BF%.	Extensively measured diet, body weight, adiposity, and the food environment. Large	Limited applicability to relatively older adults. Causality cannot be inferred because of its

Reference	Population (age, group, place)	Aim	Main outcomes	Strengths	Limitations
		between exposure to takeaway outlets, takeaway food consumption, and adiposity.	Restraint was negatively associated with takeaway consumption, but positively associated with BF%.	sample size with characteristics that broadly represent the regional United Kingdom population.	cross-sectional study design. Food outlet data is from 2011, dating the results. Uses the TFEQ-R18.
Hootman et al. (2018)	• n=264 college students; ≥18 years • US	To evaluate sex differences in stress, emotional eating, tendency to overeat, and restrained eating behaviour, and determine associations between psycho-behavioural constructs and anthropometry, adiposity, and weight gain.	Higher susceptibility to external cues and emotions was associated with greater weight, BMI, and WC. Males with higher perceived stress subsequently gained significantly more weight in the first semester, but no such relation was evident in females.	Stratified random sampling of participants. Sample reflected the wider population. High-quality data collected by trained staff using an established protocol using DXA measures. A high scope, quality and variety of the indicators assessed.	Data collected 2011–2012, dating results. Ethnicity data was not collected. 91 participants were lost to follow-up. Generalisability is limited to college students with similar demographics. Causality cannot be inferred because of its cross-sectional study design. Uses TFEQ-R18.
Jacob et al. (2023)	• n=303 adults; aged 20-55 years with overweight or obesity • Quebec, Canada	To assess if eating behaviours mediate the association between satiety responsiveness and EI.	The association between satiety and energy intake was mediated by susceptibility to hunger, internal hunger, and external hunger. Susceptibility to hunger and food cravings partly explained the susceptibility to overeating among individuals with low satiety responsiveness.	Large sample size, equal sex ratio. The use of standardised procedures and validated questionnaires. Laboratory measures of EI. Considered underreporting of EI in analysis.	EI was self-reported. Causality cannot be inferred because of its cross-sectional study design. The generalisability of results is limited to individuals with overweight and obesity.

Reference	Population (age, group, place)	Aim	Main outcomes	Strengths	Limitations
Pacheco et al. (2021)	• n=555 young adults; mean age 22.6 • Chile	To assess the association between eating behaviour scores and body composition.	Restraint was positively associated with obesity, defined by BMI, BF%, and central obesity. Emotional eating was related to obesity, defined by BF% and central obesity in men and women. Uncontrolled eating was not associated with adiposity.	Three adiposity measures (by DXA) for high accuracy. Measures were collected by trained personnel following standardised procedures. Examined relationships beyond the presence or absence of obesity and adiposity.	Limited generalisability of findings to low-to-middle–income young adults in Santiago, Chile. Potential social desirability bias. Causality cannot be inferred because of its cross-sectional study design. Uses TFEQ-R18.
Shepherd (2018)	• n=368; NZ-European, Māori and Pacific women; 16-45 years, in the EXPLORE study. • NZ	To investigate eating behaviours as predictors of different body composition factors and dietary intake.	Pacific women were significantly more likely to have higher hunger, external hunger, disinhibition, and habitual disinhibition than NZE women. Restraint was higher in NZE than Pacific women. Disinhibition was significantly higher in the apparent-fat profile. Restraint, Disinhibition, Habitual Disinhibition and Emotional Disinhibition were the most significant predictors of BMI.	Unique research on the predictors of obesity in NZ women in terms of TFEQ factors and sub-factors. The first study to explore an array of body composition measurements and the first to shed light on the eating behaviours of NZE, Māori, and Pacific women.	Causality cannot be inferred because of its cross-sectional study design. Did not adjust for confounding factors. Only women participants. Unbalanced ethnic ratio, a higher number of NZE than Māori and Pacific women. Unbalanced apparent-fat profile, normal-fat to hidden-fat profiles ratio.
Shiozawa et al. (2020)	• n=56 healthy adults; 20–27 years	To examine the correlation between eating behaviour and BMI, the correlation between eating	There was a significant correlation between restraint and BMI only in females and between hunger and BMI only in males. Disinhibition and	A unique investigation on masticatory performance, BMI and eating behaviours.	Limited generalisability of findings to healthy young adults, University students and staff in Japan.

Reference	Population (age, group, place)	Aim	Main outcomes	Strengths	Limitations
	• Japan	behaviour and masticatory performance (bite size and eating speed), and the effects of gender on these correlations.	BMI were significantly correlated in both genders. There was a significant correlation between bite size and hunger only in males and between eating speed and disinhibition in both genders.		
Systematic Review / Meta-Analysis					
Bryant et al. (2019)	• 76 articles from 2013–2018 which assessed TFEQ in adults (>18 years) normal weight or overweight/obese.	To explore the roles of the TFEQ Restraint and Disinhibition in relation to adult obesity and eating disturbance (ED) were reviewed.	Restraint has a mixed impact on weight regulation, diet quality, and vulnerability to ED. It is related detrimentally to weight regulation, diet, and psychopathology, yet can serve as a protective factor. Disinhibition is potently related to increased obesity, poorer diet, hedonically driven food choices, and a higher susceptibility to ED.	Robust literature search that included a wide range of studies with varied participants, making the generalisability of findings high.	Literature search was restricted to English language. Focuses on Restraint and Disinhibition, not hunger.

N: sample size, TFEQ: three-factor eating questionnaire, BMI: body mass index, BF%: body fat percentage, WC: waist circumference, DXA: dual x-ray absorptiometry, EI: energy intake, NZE: New Zealand European, NZ: New Zealand, ED: eating disturbance. The studies by Blumfield et al. (2018) and Hootman et al. (2018) were included in the review by Bryant et al. (2019).

2.4 Current research on the eating behaviours of low-carb diet users

When considered independently, research on low-CHO diets and eating behaviours is extensive. However, studies that investigate the relationship between these two areas are limited, yielding varied outcomes characterised by positive, conflicting, or nonsignificant results. The available literature is discussed here. A non-randomised controlled study involving 19 adults examined the impact of a prescribed 4-week CHO-restricted diet (14% CHO, 58% fat, 28% protein) on TFEQ eating behaviours. The study showed a significant increase in dietary restraint by 102% and a reduction in disinhibition and hunger scores by 17% and 22%, respectively (Anguah et al., 2019). It was also reported that as restraint increased, food cravings decreased, particularly for high-fat foods. This effect is likely due to the high-fat nature of the low-CHO diet, which does not restrict fat intake. Such a reduction in cravings from following a low-CHO diet may help to promote weight loss for individuals with a preference for high-fat foods. This diet may be less effective for those with a high affinity for CHO-based foods, given the CHO constraints that could make diet adherence difficult. In contrast, Phelan et al. (2007) found that self-reported low-CHO dieters showed significantly lower restraint scores than other dieters and consumed more calories per day despite their level of weight loss being the same. Unfortunately, both studies utilised the original TFEQ and lacked the data to analyse the sub-factors of restraint (flexible vs rigid) (Stunkard & Messick, 1985). This makes it quite unclear why overall restraint has increased and decreased in low-CHO dieters.

A 12-week uncontrolled intervention study involving 35 obese adults produced significant reductions in emotional disinhibition and external hunger eating following a ketogenic diet (5-10% CHO, >75% fat, 20% protein) using the Dutch eating behaviour questionnaire (Mohorko et al., 2019). These findings indicate that CHO restriction may reduce an individual's susceptibility to emotions and external hunger cues influencing food intake. A 2014 study perceived a low-CHO diet (20–50 g/day of CHO) significantly decreased emotional disinhibition, hunger, and disinhibition and increased dietary restraint (Saslow et al., 2014). However, these same effects were observed in the control group that followed a moderate-CHO diet (45% to 50% EI from CHO). This implies that a diet with supportive behavioural change classes may be successful irrespective of macronutrient profiles. Contrary to the above studies, an RCT observed no significant changes in eating behaviour among 74 overweight Chinese women adhering to a low-CHO diet (10% CHO, 65% fat, 25% protein) for four weeks (Hu et al., 2022). However, this study employed the Dutch Eating Behaviour Questionnaire instead of the TFEQ, complicating comparisons.

The existing research on eating behaviours and low-CHO diets is constrained by a scarcity of studies, many of which have limitations. The predominant drawbacks include short study durations, with the majority lasting only 4 weeks (Anguah et al., 2019; Hu et al., 2022) or 3 months (Mohorko et al., 2019; Saslow et al., 2014). These investigations often feature small sample sizes, ranging from 18 to 74 participants (Anguah et al., 2019; Hu et al., 2022; Mohorko et al., 2019; Saslow et al., 2014), limiting the generalisability of findings. The participant cohorts in these studies exhibit diversity in ethnicities, BMIs, educational backgrounds, health conditions, and gender, further complicating the generalisation of results to the broader population. Notably, certain studies (Anguah et al., 2019; Mohorko et al., 2019; Phelan et al., 2007) lack a non-low-CHO control group, preventing a comprehensive comparison of effects. The reliance on self-reported food records introduces potential under-reporting and social desirability, along with the inherent risk of inaccuracies in dietary assessments (Hu et al., 2022; Mohorko et al., 2019; Phelan et al., 2007; Saslow et al., 2014). Furthermore, the studies vary in macronutrient intakes, primarily stemming from the absence of a universally defined low-CHO diet. This lack of consistency poses a challenge in drawing precise conclusions about the specific impact of low-CHO diets on eating behaviours.

To address these limitations, future research endeavours should prioritise the incorporation of large and diverse sample sizes that accurately reflect the demographics of the broader population. Extended study durations, surpassing the commonly observed short-term durations, are crucial for investigating the long-term effects of low-CHO diets, with a suggested timeframe exceeding 6 months. Additionally, including a control group in study designs is imperative for comparing outcomes and enhancing the conclusions drawn from the research.

2.6 Conclusion

The prevalence of dieting is high, driven by the escalating rates of obesity. Among the various dietary approaches individuals pursue, CHO restriction holds particular appeal. Low-CHO diets have demonstrated efficacy in promoting rapid weight loss and inducing alterations in body composition in the short term. However, the long-term evidence supporting their effectiveness is comparatively less robust. It is widely acknowledged that eating behaviours significantly influence dietary intake, ultimately impacting body weight and composition. Nevertheless, a comprehensive understanding of the eating behaviours exhibited by adherents of low-CHO diets remains an area warranting further investigation. Exploring the body composition and eating behaviours of individuals following low-CHO diets is crucial for gaining insights into the long-term sustainability, potential health risks, and effectiveness of such dietary approaches in weight management and overall health outcomes.

Chapter 3

Research Study Manuscript

Investigating the Eating Behaviours of Free-Living Low-Carbohydrate Diets Users in New Zealand

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Keywords: carbohydrate restriction, ketogenic, restraint, hunger, disinhibition, body composition, health.

3.1 Abstract

Many individuals adopt a low-carbohydrate (low-CHO) diet for weight management. While eating behaviours significantly impact dietary intake and health, their relation to low-CHO diets is rarely explored. This cross-sectional study investigated body compositions, dietary intakes, and eating behaviours and how they differed between CHO intake levels among free-living, self-reported low-CHO diet users in NZ. The sixty-nine participants had a mean age of 35 years and a median diet adherence of 9.5 months. They completed a health and demographics questionnaire, the Three-Factor Eating Questionnaire (TFEQ), a 4-day dietary record, and provided anthropometric measurements. Participants were grouped into three CHO intake ranges: moderately low (ML) (>100 and <150 g/day) (n=10), low (L) (≥50 and <100 g/day) (n=20), and very-low (VL) (<50 g/day of CHO) (n=39). Their mean macronutrient intakes as a contribution to total energy (%EI) were 12.5 ± 8.28% for CHO, 58 ± 11.3% for total fat, 22.6 ± 6.98% for saturated fatty acids (SFA), and 24.5 (23.3-25.9)% for protein. CHO (%EI) were replaced with total fat and SFA (%EI), and not protein. They had a mean body fat percentage (BF%) of 27.9 ± 9.9% and a median muscle mass of 28.0 [25.2-33.2] kg. Body composition was similar in each CHO group. Overall, participants showed high restraint, low rigid and flexible restraint, low disinhibition, low habitual, situational, and emotional disinhibition, low hunger, and low internal and external hunger. TFEQ scores did not differ between CHO groups. Restraint was positively associated with CHO (%EI) ($r = 0.34$, $p = <0.01$) and inversely associated with total fat ($r = -0.35$, $p = <0.01$) and SFA (%EI) ($r = -0.31$, $p = 0.01$). CHO intake (%EI) was positively correlated with rigid restraint ($r = 0.27$, $p = <0.01$) and flexible restraint ($r = 0.34$, $p = <0.01$). Restraint correlated with BF% ($r = 0.28$, $p = 0.02$), and each increasing restraint score predicted a 0.6% increase in BF%. As diet duration increased, BMI ($r = -0.27$, $p = 0.03$), WC ($r = -0.28$, $p = 0.03$), and habitual disinhibition ($r = -0.27$, $p = 0.03$) decreased. The voluntary choice of free-living low-CHO dieters may uniquely shape their eating behaviours compared to those on prescribed low-CHO diets, impacting aspects such as adherence, motivation, and the psychological relationship with food. It is important to consider the associations eating behaviours can have with dietary intake and body composition in low-CHO diets in determining the suitability of such a diet.

3.2 Introduction

Dieting is prevalent, reflecting the growing concern over obesity and its associated health implications (World Health Organization, 2021). Many individuals modify their dietary habits to reduce body weight or alter body composition through various means (Utter et al., 2012). In New Zealand (NZ), approximately two-thirds (65.5%) of the population are overweight or obese and are at elevated risk of heart disease, stroke, diabetes, cancers, and premature mortality (Ministry of Health, 2021; World Health Organization, 2021). Despite more than half of the NZ population attempting weight loss in 2018, popular diets often yield limited success, contributing to the persistent obesity rates (Freire, 2020; Ministry of Health, 2019).

One prevalent type of diet is the low-carbohydrate (low-CHO) diet, ranking as the sixth most popular in NZ (Maclaren et al., 2017). Low-CHO diets involve restricting CHO below dietary guidelines, typically to no more than 150 g/day or 10-20 % of total energy intake (EI) (Fields et al., 2016). Low-CHO dieters replace CHO foods (e.g. bread, cereals, and rice) with increased protein (e.g., meat, fish, and eggs) and fat (e.g., oils, nuts, and seeds) intake. Intakes may vary from 30-50% of EI for fat and 20-30% for protein (Bravata et al., 2003; Oh et al., 2019), deviating from national guidelines recommending CHO to contribute 45-65% of EI, fats at 20-35%, and proteins at 15-25% (National Health and Medical Research Council, 2005). Low-CHO diets generally prioritise reducing CHO intake to achieve ketosis, a metabolic state where the body utilises fat over glucose for energy (Oh et al., 2019). Reducing CHO intake can decrease blood sugar and insulin levels, mitigating the risk of certain non-communicable diseases such as type 2 diabetes (Ludwig & Ebbeling, 2018; Westman et al., 2007).

The impact of a low-CHO diet on body composition is a well-researched topic (Gram-Kampmann et al., 2022; Naude et al., 2022; Romano et al., 2019). Body composition describes the proportion of fat, muscle, and other body tissues and is a crucial determinant of overall health (Holmes & Racette, 2021). Achieving a healthy body composition through diet and lifestyle is essential for optimal health. Excessive body fat is associated with various health risks, like cardiovascular disease and diabetes, while insufficient muscle mass affects strength, mobility, and metabolism (Fitch & Bays, 2022; Holmes & Racette, 2021). Dietary choices play a vital role in body composition, with a balanced diet, essential nutrients, and controlled caloric intake recommended (Drenowatz et al., 2014; Holmes & Racette, 2021; Naude et al., 2022).

Short-term studies suggest that low-CHO diets can lead to rapid weight loss and favourable changes in body composition, such as reduced body fat percentage (BF%) and improved muscle mass (Dinu et al., 2020; Naude et al., 2022; Silverii et al., 2022). However, the supporting evidence is limited, conflicting and primarily focused on short-term effects. The low-CHO diet poses potential risks, including nutritional deficiencies from reduced intake of vegetables, fruits, and whole grains, digestive issues due to insufficient dietary fibre (Reynolds et al., 2019), associations with disordered eating (Utter et al., 2012), cardiovascular risks due to high saturated fat consumption (National Health and Medical Research Council, 2005), and protentional side effects of ketosis, such as fatigue, headaches, and bad breath (Naude et al., 2022).

Eating behaviours significantly impact dietary choices, weight management, psychological well-being, and overall health. Eating behaviours are categorised into three main factors with sub-factors, namely restraint (rigid and flexible), disinhibition (emotional, situational, and habitual), and hunger (internal and external). Restraint describes conscious effort to control food intake, with rigid restraint characterised by an 'all-or-nothing' approach with strict rules and guilt associated with rule violations, and flexible restraint allows for occasional indulgences without guilt while maintaining conscious control over health. Disinhibition refers to losing control of eating in response to various triggers, including emotional states (i.e., sadness or boredom), specific situations and environmental contexts (i.e., social gatherings), or habitual patterns (i.e., late-night snacking). Hunger pertains to the perception of hunger cues encompassing internal physiological cues that indicate the need for food, like stomach cramping, and external triggers, such as environmental or social cues, regardless of a physiological need for food (Bond et al., 2001; Stunkard & Messick, 1985). The three-factor eating questionnaire (TFEQ) is a validated tool that assess susceptibility to each factor and sub-factor (Bond et al., 2001; Westenhoefer et al., 1999).

Understanding eating behaviours provides insight into dietary practices and psychological relationships with food, aiding in the identification of suitable dietary interventions (Bryant et al., 2019). Certain behaviours have been associated with improved weight management; for example, rigid restraint may contribute to unhealthy or disordered eating patterns contributing to increased weight, while flexible restraint is linked to balanced diets and sustainable body weights (Bryant et al., 2019; Johnson et al., 2012). Increased susceptibility to disinhibition and hunger, including their sub-factors, correlates with higher BMI and increased BF% (Blumfield et al., 2018; Bryant et al., 2019; Jacob et al., 2023; Shepherd, 2018). While some studies have explored to association between eating behaviours and low-CHO diets, comprehensive examinations of this relationship are limited (Anguah et al., 2019; Hu et al., 2022; Mohorko et al., 2019).

Despite the significant public interest and adherence to low-CHO diets, more evidence is needed to describe the eating behaviours and body compositions of individuals adopting this diet in NZ. Therefore, this study aimed to investigate the eating behaviours and body compositions of free-living low-CHO diet users. The data analysed here was collected as part of a larger study designed to observe various health effects of low-CHO diet users (Knightbridge-Eager, 2020; Rassam, 2020).

3.3 Materials and Methods

3.3.1 Design

The wider LOCA (Low-carbohydrate diet) study, a cross-sectional exportation at the Massey University's Human Nutrition Research Unit (HNRU), examined the dietary practices, behaviours, lifestyle, and metabolic markers of low-CHO diet users in Auckland, NZ, aged 20-45. The present sub-study specifically aimed to explore the eating behaviours and body compositions of those low-CHO diet users.

3.3.2 Participants

The sub-study's inclusion criteria required participants who had followed a self-reported low-CHO diet for at least four months; were men or women aged 20-45; were not pregnant or lactating; had no history of bariatric surgery; were generally in good health; and were not taking medications that may influence the outcome measures, such as blood lipids/cholesterol, blood sugar, or blood pressure.

The sample size of 69 was estimated to provide 70% power at a significance level of $p = 0.0167$ to detect a large effect size f of 0.4 (G*Power 3.1.9.4) for comparing nutrient intakes between CHO groups (Faul et al., 2009).

3.3.3 Ethics and Procedures

The LOCA study adhered to the ethical guidelines outlined in the Declaration of Helsinki (World Medical Association, 2018), and received ethical approval from the Massey University Human Ethics Committee: Southern A Committee, application SOA18/22.

Recruitment and data collection occurred over nine months, from September 18, 2018, to June 15, 2019. Various recruitment strategies were employed, including social media (Facebook and Instagram), gym posters, and 'word-of-mouth' referrals. Those interested underwent online screening, and upon meeting the inclusion criteria, received an online information sheet detailing the study requirements and procedures and a consent form. Enrolled participants scheduled an appointment at Massey University's HNRU in Albany, with the right to withdraw at any point emphasised.

To ensure participant confidentiality, unique number identifiers were assigned, and all personal information was anonymised for data analyses. Data were securely stored in locked filing cabinets, and computer files were password protected. Researchers signed confidentiality agreements and accessed only relevant data for their specific tasks.

3.3.4 Measures

Demographic data

At the HNRU, participants completed the online Health and Demographics Questionnaire (HDQ) using SurveyMonkey (Appendix A1). The demographic data, such as age, gender, ethnicity, income, supplement use, and health, was coded in Excel, then transferred to SPSS (IBM SPSS Software, 2017) for analysis. Supplement use was examined to describe the population and not investigated further due to the limited sample size.

Dietary intake data

Participants submitted a four-day weighted food record before their data collection appointment, covering all food, beverages, and supplements on randomised non-consecutive days, including one weekend day. A provided template and instructional video aided in accurate completion. Research assistants reviewed the records, clarifying ambiguities. Food records were entered into FoodWorks 9 (Xyris, 2019), cross-checked, and analysed using the NZ FOODfiles 2016 database and Australian databases when needed. Assumptions were made for items not in the databases, supplements were excluded unless consumed as food, and medications were excluded.

Eating behaviour data

Participants completed the self-administered three-factor eating questionnaire (TFEQ), including 51 questions on restraint (21 items), disinhibition (16 items) and hunger (14 items) and their respective sub-factors (Stunkard & Messick, 1985) (Appendix A2). The responses were scored 0 or 1, and factors were ranked according Westenhoefer et al. (1999), Bond et al. (2001) and Lesdema et al. (2012). Restraint and disinhibition were ranked low (≤ 7) or high (> 7) and hunger was ranked low (≤ 5) or high (> 5) (Lesdema et al., 2012). Additional TFEQ coding details can be found in Appendix A3.

Anthropometric measurements

Trained researchers followed the International Society for the Advancement of Kinanthropometry (ISAK) protocols (Marfell-Jones et al., 2012) to obtain anthropometric measurements. Height was measured using a stadiometer (Marfell-Jones et al., 2012). Weight and body composition (BF%, body fat mass (BFM), and muscle mass) were assessed using bioelectrical impedance analysis (BIA; InBody230, Biospace Co. Ltd, Seoul). BFM (kg) represents the body's fat weight, while BF% is the proportion of BFM in relation to the total body weight. Body mass index (BMI) was calculated (BMI (kg/m^2). Waist and hip circumferences were assessed with a Lufkin tape. Anthropometric measurements were conducted twice for precision; a third followed if the initial two differed by > 1% (Marfell-Jones et al., 2012).

3.3.5 Statistical Analysis

Statistical analyses were performed using SPSS® (IBM SPSS version 25.0). Data normality was assessed using Kolmogorov-Smirnov and Shapiro-Wilk tests, and histograms. Variables deviating from normality underwent logarithmic transformation (log base 10) then, re-evaluated for normality. Normally distributed variables were reported as mean and standard deviation, while transformed variables were expressed as geometric mean with a 95% confidence interval. Non- normally distributed variables were presented as medians and interquartile ranges (25th - 75th percentiles). Categorical variables were expressed as proportions or n (%). TFEQ scores were reported as median [25th-75th percentiles] to show a range, however, but treated as normal data. A low-CHO diet was defined as containing ≤150 g of CHO per day. To compare the effects of varied levels of CHO restriction, participants were grouped into three CHO intake ranges: moderately low (ML) (≥100 and <150 g/day), low (L) (≥50 and <100 g/day), and very-low (VL) (<50 g/day). Participants exceeding 150 g/day were excluded from statistical analysis (n=5). Variance in energy intake was controlled for in nutrients expressed as a percentage of total EI. For total household income with multiple responses, averages of each selected income bracket were summed for an average income.

Chi-squared tests determined nominal data *p*-values. ANCOVA controlling for gender with assumptions met determined *p*-values for normally distributed scale data, and Quade's test controlling for gender determined *p*-values for non-normally distributed data. For significant differences ($p < 0.05$), post-hoc Bonferroni corrections identified statistically different groups ($p < 0.017$) (Field, 2013). Variables tested further were treated as normal, in agreement with the central limit theorem (Field, 2013). Pearson's correlations, followed by partial correlations controlling for gender and age, were conducted for macronutrient intakes (%EI), TFEQ scores, body composition measures, and diet duration to calculate r values. Significant Pearson's r values ($p < 0.05$) led to multiple linear regression analyses using the enter method. Assumptions (autocorrelation, multicollinearity, linearity, and normality) were met. Model 1 was unadjusted, and Model 2 was adjusted for gender and age.

3.4 Results

Initially, 89 participants qualified for the LOCA study, 74 completed all data requirements, and 69 met the criteria for analysis in this sub-study. The participant recruitment and data processes is presented in Figure 3.1. The 15 who did not participate either did not make or attend an appointment. The excluded group (*n* = 5) had CHO intakes that exceeded 150 g/day, with a mean intake of 234.9 g/day, and a mean age of 28.8 years; two were male, three were female, and three were of NZ-European ethnicity; one was Brazilian, and one was Indian.

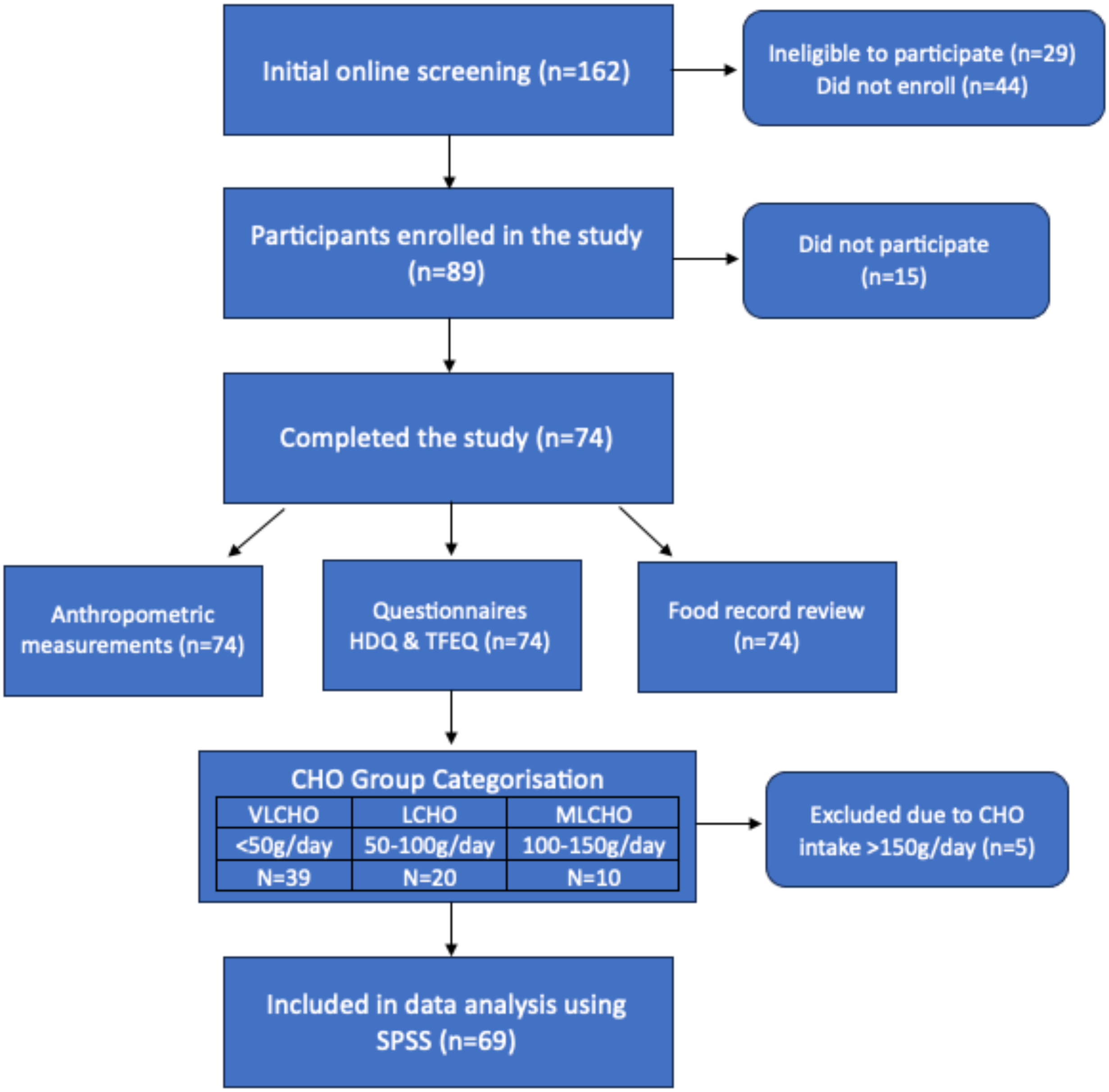

Figure 3.1

Participant Recruitment and Data Process

HDQ: Health and Demographics Questionnaire; TFEQ: Three Factor Eating Questionnaire; CHO: carbohydrate; VLCHO: very low carbohydrate; LCHO: low carbohydrate; MLCHO: moderately low carbohydrate.

3.4.1 Participant demographics

Table 3.1 displays the demographics of the 69 participants, categorised by CHO group (CHO intake in grams). Participants had a mean age of 35 ± 7 years and were predominantly women (74%). Most were of

NZ-European ethnicity (71%), had completed tertiary education (79.7%), worked full-time (63.8%), and had a regular daytime working pattern (66.7%). Nearly half never or rarely consumed alcohol (44.9%), the majority did not smoke (79.7%), only 4.3% reported following dietary restrictions other than low CHO intakes, and 59.4% took supplements. The median duration following a low-CHO diet was 9.5 [5.0-20.3] months. No significant differences were found between the CHO groups for participant demographics.

Table 3.1

Demographic Characteristics of all Participants and CHO Groups (n= 69)

Variables	Completed Responses	VLCHO *n = 39*	LCHO *n = 20*	MLCHO *n = 10*	*p*-value
Demographics					
Age (years)					0.629
	35.1±7.39	35.9±6.88	34.1±7.88	34.2±8.8	
Gender, n (%)					0.408
Male	18 (26%)	8 (20.5%)	6 (30%)	4 (40%)	
Female	51 (74%)	31 (79.5%	14 (70%)	6 (60%)	
Highest level of education, n (%)					0.428
Secondary school or other trade certificate or diploma	14 (20.2%)	11 (28.2%)	2 (10%)	1 (10%)	
Tertiary education	55 (79.8%)	28 (71.8%)	18 (90%)	9 (90%)	
Ethnicity, n (%)					0.257
New Zealand European	49 (71%)	30 (76.9%)	12 (60%)	7 (70%)	
Māori	1 (1.4%)	0 (0%)	1 (5%)	0 (0%)	
Asian	7 (10.1%)	1 (2.6%)	4 (20%)	2 (20%)	
Other European	8 (11.6%)	6 (15.4%)	2 (10%)	0 (0%)	
Other	4 (5.9%)	2 (5.1%)	1 (5%)	1 (10%)	
Working hours, n (%)					0.368

Variables	**Completed Responses**	**VLCHO** *n = 39*	**LCHO** *n = 20*	**MLCHO** *n = 10*	***p*-value**
Full time	44 (69.8%)	25 (73.5%)	11 (57.9%)	8 (80%)	
Part-time	19 (30.2%)	9 (26.5%)	8 (42.1%)	2 (20%)	
Current working pattern, n (%)					0.433
Daytime with no shifts	46 (71.9%)	21 (60%)	17 (89.5%)	8 (80%)	
Rotating shifts with nights	4 (6.3%)	3 (8.55%)	0 (0%)	1 (10%)	
Rotating shifts without nights	1 (1.6%)	1 (2.9%)	0 (0%)	0 (0%)	
Irregular or variable	8 (12.5%)	7 (20%)	1 (5.2%)	0 (0%)	
Other	5 (7.7%)	3 (8.55%)	1(5.3%)	1 (10%)	
Living style, n (%)					0.242
Lives alone	1 (1.4%)	0 (0%)	1 (5%)	0 (0%)	
Lives with family	33 (47.8%)	16 (41%)	12 (60%)	5 (50%)	
Lives with a partner	25 (36.2%)	18 (46.2%)	5 (25%)	2 (20%)	
Flatting	10 (14.6%)	5 (12.8%)	2 (10%)	3 (30%)	
Total monthly income, n (%)					0.437
$0-$3000	7 (11.5%)	3 (8.3%)	2 (12.5%)	2 (22.3%)	
$3001-$8000	31 (50.8%)	19 (52.8%)	8 (50%)	4 (44.4%)	
$8001 or more	23 (37.7%)	14 (38.9%)	6 (37.5%)	3 (33.3%)	
Alcohol intake, n (%)					0.49
Never or very rarely	31 (44.9%)	17 (43.6%)	7 (35%)	7 (70%)	

Variables	**Completed Responses**	**VLCHO** *n = 39*	**LCHO** *n = 20*	**MLCHO** *n = 10*	***p*-value**
One drink per week	13 (18.9%)	9 (23.1%)	3 (15%)	1 (10%)	
More than one drink per week	25 (36.2%)	13 (33.3%)	10 (50%)	2 (20%)	
Smoking status, n (%)					0.554
Non-smoker	55 (79.7%)	29 (74.4%)	18 (90%)	8 (80%)	
Current smoker	4 (5.8%)	3 (7.7%)	1 (5%)	0 (0%)	
Former smoker	10 (14.5%)	7 (17.9%)	1 (5%)	2 (20%)	
Ethical/cultural dietary restrictions, n (%)					0.292
No	65 (95.6%)	38 (97.4%)	17 (89.5%)	10 (100%)	
Yes	3 (4.4%)	1 (2.6%)	2 (10.5%)	0 (0%)	
Allergies or intolerances,, n (%)					0.065
No	52 (76.5%)	25 (65.8%)	18 (90%)	9 (90%)	
Yes	16 (23.5%)	13 (34.2%)	2 (10%)	1 (10%)	
Current use of medication, n (%)					0.525
No	48 (69.6%)	29 (74.4%)	12 (60%)	7 (70%)	
Yes	21 (30.4%)	10 (25.6%)	8 (40%)	3 (30%)	
Current use of hormonal contraception, n (%)					0.845
No	59 (85.5%)	34 (87.2%)	17 (85%)	8 (80%)	
Yes	10 (14.5%)	5 (12.8%)	3 (15%)	2 (20%)	
Supplement intake, n (%)					0.101

Variables	Completed Responses	VLCHO *n = 39*	LCHO *n = 20*	MLCHO *n = 10*	*p*-value
No	27 (39.7%)	14 (35.9%)	6 (31.6%)	7 (70%)	
Yes	41 (60.3%)	25 (64.1%)	13 (68.4%)	3 (30%)	
Eating speed, n (%)					0.075
Quickly	19 (27.5%)	10 (25.6%)	3 (15%)	6 (60%)	
Moderately paced	48 (69.6%)	27 (69.2%)	17 (85%)	4 (40%)	
Slowly	2 (2.9%)	2 (5.2%)	0 (0%)	0 (0%)	
Duration on a low-CHO diet (months)					
Median	9.5 [5-20]	9 [5-18]	11.5 [6-25]	9 [4-20]	0.528

Normally distributed scale data is reported as mean ± SD or as mean (95% confidence interval) following transformation (Log10). Non-normally distributed data reported as median [25th-75th percentiles]. Nominal data *p* values determined by chi-squared tests. Normally distributed scale data *p*-values determined by ANCOVA controlling for gender with assumptions met. Non-normally distributed data *p* values determined by Quade's test controlling for gender. Percentages were calculated by the number of completed responses within the total and CHO groups. CHO intake ranges are defined as very-low CHO (VLCHO) (< 50 g/day), low-CHO (LCHO) (50-100 g/day) and moderately-low CHO (MLCHO) (100-150 g/day).

3.4.2 Anthropometry

No significant body composition differences were found between CHO groups (Table 3.2). The total group's mean energy intake was 7333 ± 2379 kJ/day. The mean macronutrient intakes expressed as grams and percentages of total EI, were: CHO 41.5 (34.7-49.7) g and 12.5 ± 8.28%, total fat 116.5 ± 46.6 g and 58.0 ± 11.3%, saturated fat (SFA) 40.4 (35.8-45.6) g and 22.6±6.98%, and protein 105.8±33.8 g and 24.5 (23.3-25.9)%. The national acceptable macronutrient distribution ranges (AMDR) are displayed next to the %EI of the macronutrients (Ministry of Health, 2011). Monounsaturated fatty acids (MUFAs) contributed 22.5 ± 5.01%, while polyunsaturated fatty acids (PUFAs) contributed 7.54 [5.96-9.42]%. The total population had a mean weight of 75.1 ± 14.8 kg, median BMI of 24.6 [22.2-28.7] kg/m^2, and mean waist circumference (WC) of 78.4±1.22. The mean BF% was 27.9 ± 9.9%, and the median BFM and muscle mass were 18.9 [13.3-27.3] kg and 28.0 [25.2-33.2] kg, respectively.

Table 3.2

Anthropometry of all participants and CHO groups (n= 69)

Variables	**All participants** *n= 69*	**VLCHO** *n = 39*	**LCHO** *n = 20*	**MLCHO** *n = 10*	***p*-value**
Weight (kg)	75.1±14.8	74.5±14.1	74.7±14.6	78.4±18.8	0.905
WC (cm)	78.4±1.22	78.2±9.8	77.5±10.5	80.9±11.5	0.68
BMI (kg/m^2)	24.6 [22.2-28.7]	24.6 [22.2-29.7]	24.8 [22.1-27.8]	24.7 [23.6-25.2]	0.803
BMI Range	18.4-39.3	18.4-33.8	19.9-36.0	21.0-39.3	
BF% (%)	27.9±9.9	29.3±9.6	27.1±9.5	24.2±11.8	0.655
BFM (kg)	18.9 [13.3-27.3]	21.1 [14.7-27.6]	18 [13-27.5]	15.3 [12.1-18.3]	0.563
Muscle mass (kg)	28.0 [25.2-33.2]	27.1 [24.8-30.9]	28.3 [25.4-33.2]	32.9 [25.3-43.1]	0.769

Scale data is presented as mean ± SD or mean (95% confidence interval) after Log10 transformation for normal distribution. Non-normally distributed data is expressed as median [25th-75th percentiles]. Nominal data *p*-values result from chi-squared tests. ANCOVA, controlling for gender with met assumptions, determines *p*-values for normally distributed scale data. Quade's test, controlling for gender, determines *p*-values for non-normally distributed data. CHO intake ranges are defined as very-low CHO (VLCHO) (<50 g/day), low-CHO (LCHO) (50-100 g/day), and moderately-low CHO (MLCHO) (100-150 g/day).

3.4.3 Dietary Intake

Energy intakes were significantly higher in the MLCHO group than in the VLCHO group (*p*= 0.003) (Table 3.3). The mean CHO intakes in grams for the VLCHO, LCHO, and MLCHO groups were 24.3 (20.8-28.4) g, 68.6 (61.6-76.3) g, and 123 (112-136) g, respectively, with significant differences observed between groups. For %EI, the corresponding values were 7.23 ± 3.24%, 16.5 ± 5.51%, and 25.3 ± 8.54%, showing significant differences between the groups. The VLCHO group had significantly higher total fat (%EI) (*p*= <0.001) and SFA (%EI) (*p*= <0.001) intakes than the LCHO and MLCHO groups. The MUFA (%EI) increased in each lower CHO intake group, with the VLCHO group showing significantly higher intake than the MLCHO group. However, no significant differences were seen between the CHO groups for absolute total fat (g), SFA (g), MUFA (g) or PUFA (g) intakes. Protein (%EI) did not differ significantly between CHO groups; however, protein intake in grams was significantly higher in the MLCHO group compared to the LCHO and VLCHO groups (Table 3.3).

Table 3.3

Dietary Intake of all participants and CHO groups (n= 69)

Variables	**All participants** *n= 69*	**VLCHO** *n = 39*	**LCHO** *n = 20*	**MLCHO** *n = 10*	***p*-value**
Energy (kJ)	7333±2379	6565±1554[a]	7806±2404	9388±3555[a]	0.003
CHO (g)	41.5 (34.7-49.7)	24.3 (20.8-28.4)[a, b, c]	68.6 (61.6-76.3)[a, b, c]	123 (112-136)[a, b, c]	<0.001
CHO %EI (45-65%)	12.5±8.28	7.23±3.24[a, b, c]	16.5±5.51[a, b, c]	25.3±8.54[a, b, c]	<0.001
CHO %EI Range	2.16-41.68	2.16-14.5	8.76-27.3	13.2-41.7	
Total fat (g)	116.5±46.6	113.8±34.6	118.3±53.9	123.1±71.7	0.995
Total fat %EI (20-35%)	58±11.3	63.5±7.56[a, b]	53.9±10.8[a]	45.1±11.4[b]	<0.001
SFA (g)	40.4 (35.8-45.6)	43.4 (38.2-49.3)	36.9 (28.2-48.5)	36.7 (22.1-61.1)	0.229
SFA %EI (<10%)	22.6±6.98	25.8±5.87[a, b]	19.4±6.29[a]	16.4±5.25[b]	<0.001
MUFA (g)	44.7±18.8	42.6±12.9	46.6±22.3	48.8±29.5	0.780
MUFA %EI	22.5±5.01	23.9±4.05[a]	21.2±5.38	17.9±4.95[a]	0.002

Variables	All participants n= 69	VLCHO n = 39	LCHO n = 20	MLCHO n = 10	*p*-value
PUFA (g)	13.9 [11.0-19.2]	12.8 [10.4-16.6]	17.8 [14.4-20.6]	14.1 [12.3-19.1]	0.102
PUFA %EI	7.54 [5.96-9.42]	7.51 [6.11-9.38]	8.10 [7.13-9.67]	5.63 [4.39-7.8]	0.055
Protein (g)	105.8±33.8	96.2±23.6^{a}	107.1±32.7^{b}	140.9±47.5$^{a, b}$	0.001
Protein %EI (15-25%)	24.5 (23.3-25.9)	24.9 (23.5-26.5)	23.3 (20.2-26.7)	25.6 (22.3-29.4)	0.434

Scale data is presented as mean ± SD or mean (95% confidence interval) after Log10 transformation for normal distribution. Non-normally distributed data is expressed as median [25th-75th percentiles]. Nominal data *p*-values result from chi-squared tests. ANCOVA, controlling for gender with met assumptions, determines *p*-values for normally distributed scale data. Quade's test, controlling for gender, determines *p*-values for non-normally distributed data. Values with the same superscript letters significantly differ based on Tukey post-hoc test and Bonferroni correction when $p < 0.017$. CHO intake ranges are defined as very-low CHO (VLCHO) (<50 g/day), low-CHO (LCHO) (50-100 g/day), and moderately-low CHO (MLCHO) (100-150 g/day).

3.4.4 TFEQ Scores

The TFEQ scores for each CHO group were presented in Table 3.4, with the highest possible score next to each factor and the cut-off points for high and low scores. The median scores for restraint, disinhibition, and hunger were 11 [8-15], 5 [3.5-7.5], and 2 [1-3], respectively. There were no significant differences in TFEQ scores between the CHO groups (Table 3.4).

Table 3.4

Three-Factor Eating Questionnaire scores of all participants and CHO groups (n= 69)

Variables		All participants n= 69	VLCHO n = 39	LCHO n = 20	MLCHO n = 10	*p*-value
Restraint (21)	Median	11 [8-15]	10 [8-14]	12 [9-17]	11 [8-18]	0.241
	Range	4-19	4-18	5-19	6-19	
	Low (≤ 7)	6 [5-7] n=12 (17%)	6 [5-7] n=9 (23%)	6 [5-7 n=2 (10%)	6 [6-6] n=1 (10%)	0.365
	High (> 7)	11 [10-15.5] n=57 (83%)	11 [10-15] n=30 (77%)	13 [10-17] n=18 (90%)	11 [9-18] n=9 (90%)	
Rigid (7)	Median	2 [1-4]	2 [1-3]	3 [1-4.50]	2 [1-6]	0.306
Flexible (7)	Median	3 [3-5]	3 [3-4]	4 [3-5.5]	3 [2-6]	0.201

Variables		All participants *n= 69*	VLCHO *n = 39*	LCHO *n = 20*	MLCHO *n = 10*	*p*-value
Disinhibition (16)	Median	5 [3.5-7.5]	5 [4-8]	5 [3-7]	7 [4-8]	0.756
	Range	1-12	2-12	1-9	2-8	
	Low (≤ 7)	4 [2-6] n=52 (75%)	4 [2-6] n=29 (74%)	4.5 [2.5-6] n=16 (80%)	4 [3-7] n=7 (70%)	0.816
	High (> 7)	9 [8-10] n=17(25%)	9 [9-12] n=10 (26%)	8.5 [8-9] n=4 (20%)	8 [8-8] n=3 (30%)	
Habitual (5)		1 [0-1]	1 [0-2]	0.5 [0-1]	1 [0-1]	0.201
Situational (5)		2 [1-3]	2 [1-3]	1 [1-3]	2 [1-3]	0.851
Emotional (3)		0 [0-2]	0 [0-2]	0 [0-2]	0.5 [0-1]	0.705
Hunger (14)	Median	2 [1-3]	2 [1-3]	1 [1-2.5]	3 [2-4]	0.119
	Range	0-11	0-11	0-4	0-6	
	Low (≤ 5)	2 [0.5-3] n=64 (93%)	1 [1-2.5] n=36 (92%)	1 [1-2.75] n=20 (100%)	2.5 [2-3] n=8 (80%)	0.136
	High (> 5)	9 [6-10.5] n=5 (7%)	10 [9-11] n=3 (8%)	0 [0-0] n=0 (0%)	6 [6-6] n=2 (20%)	
Internal (6)		0 [0-1]	0 [0-1]	0 [0-1]	0 [0-1]	0.564
External (6)		1 [0-1]	1 [0-1]	1 [0-1]	1 [1-2]	0.335

CHO intake ranges are defined as very-low CHO (VLCHO) (<50 g/day), low-CHO (LCHO) (50-100 g/day), and moderately-low CHO (MLCHO) (100-150 g/day). The number of questions for each TFEQ factor is displayed beside it. TFEQ scores are presented as median [25th-75th percentiles]. TFEQ *p*-values result from chi-squared tests. Interpretation of TFEQ scores: Restraint (Low= 0-7, High= 8-21); Flexible Restraint (Low= 0-3, High 4-7); Rigid restraint (Low= 0-3, High= 4-7); Disinhibition (Low= 0-7, High=8-16); Habitual Disinhibition (Low= 0-2, High= 3-5); Emotional Disinhibition (Low= 0-1, High= 2-3); Situational Disinhibition (Low= 0-2, High=3-5); Hunger (Low=0-5, High= 6-14); Internal Hunger (Low= 0-3, High 4-6); External Hunger (Low= 0-3, High= 4-6).

3.4.5 Correlations between dietary intake, anthropometry, diet duration and TFEQ scores

Table 3.5 displays the correlations between macronutrient intakes (%EI), TFEQ scores, body composition parameters, and diet duration. The following data presented are controlled for gender and age unless specified differently. Concerning dietary intake data, restraint was significantly correlated with CHO (%EI) (r = 0.34, p = <0.01) and inversely correlated with total fat (%EI) (r = -0.35, p = <0.01) and SFA (%EI) (r = -0.31, p = 0.01). No significant correlations were observed between macronutrient intake and disinhibition or hunger. Protein (%EI) did not correlate with any TFEQ factors.

CHO intake (%EI) was positively correlated with rigid restraint (r = 0.27, p = <0.01) and flexible restraint (r = 0.34, p = <0.01). Opposingly, total fat (%EI) negatively correlated with rigid restraint (r = -0.3, p = 0.01) and flexible restraint (r = -0.34, p = <0.01). SFA (%EI) also correlated negatively with rigid restraint (r = -0.32, p = 0.01) and flexible restraint (r = -0.34, p = <0.01). Protein (%EI) was positively correlated with rigid restraint (r = 0.24, p = 0.04); however, this significance disappeared after controlling for gender and age (r = 0.22, p = 0.07).

Body fat (%) was positively correlated with restraint (r = 0.28, p = 0.02) and flexible restraint (r = 0.24, p = 0.047). Before controlling, rigid restraint, habitual disinhibition, and external hunger significantly correlated to BF%. Contrastingly, muscle mass correlated negatively with rigid restraint (r = -0.26, p = 0.04) and flexible restraint (r = -0.32, p = 0.01). A positive correlation between muscle mass and external hunger lost significance after controlling for gender and age. Body weight, WC, BMI, and BFM did not significantly correlate to TFEQ factors or sub-factors.

Diet duration showed a negative correlation with BMI (r = -0.27, p = 0.03), WC (r = -0.28, p = 0.03), and habitual disinhibition (r = -0.27, p = 0.03).

Table 3.5

Correlations of Dietary Intake (%EI), Anthropometry, and Diet Duration with Three Factor Eating Questionnaire Factors and Sub-Factors

Variables	R		FR		RR		D		HD		SD		ED		H		IH		EH		Diet D (months)	
	r	*p*	r	*p*	r	*p*	r	*p*	r	*p*	r	*p*	r	*p*	r	*p*	r	*p*	r	*p*	r	*p*
Dietary intake (%EI)																						
CHO	0.34	<0.01*#	0.34	<0.01*#	0.27	<0.01*#	0.06	0.64	0.01	0.96	0.03	0.81	0.04	0.73	0.08	0.52	0.02	0.89	0.1	0.45	0.16	0.22
Total fat	-0.35	<0.01*#	-0.34	<0.01*#	-0.32	0.01*#	-0.11	0.39	0.06	0.65	-0.12	0.36	-0.13	0.31	-0.11	0.38	-0.05	0.69	-0.13	0.3	-0.2	0.12
SFA	-0.31	0.01*#	-0.35	<0.01*#	-0.32	0.01*#	-0.13	0.29	<0.01	0.98	-0.07	0.59	-0.19	0.12	-0.06	0.61	<-0.01	0.98	-0.07	0.57	-0.23	0.07
Protein	0.2	0.11	0.2	0.49	0.22	0.07#	-0.01	0.91	-0.13	0.3	0.08	0.5	-0.01	0.93	0.12	0.32	0.07	0.58	0.17	0.17	0.16	0.22
Anthropometry																						
Weight (kg)	0.01	0.94	-0.1	0.45	-0.09	0.47	0.05	0.71	0.05	0.67	<0.01	0.98	-0.01	0.99	-0.07	0.55	<-0.01	0.99	-0.06	0.63	-0.16	0.2
WC	0.11	0.39	0.03	0.84	0.01	0.96	0.13	0.31	0.15	0.22	0.02	0.87	0.04	0.75	-0.04	0.77	0.02	0.85	-0.1	0.41	-0.28	0.03*#
BMI	0.15	0.24	0.03	0.80	0.04	0.74	0.08	0.51	0.14	0.27	0.01	0.95	-0.02	0.87	-0.1	0.41	-0.05	0.71	-0.15	0.22	-0.27	0.03*#
BF%	0.28	0.02*#	0.24	0.05#	0.21	0.08#	0.08	0.51	0.23	0.07#	-0.02	0.89	-0.06	0.65	-0.02	0.86	0.09	0.49	-0.1	0.4#	-0.08	0.55
BFM (kg)	0.18	0.15	0.12	0.34	0.1	0.43	0.05	0.69	0.15	0.24	-0.04	0.75	-0.05	0.66	-0.05	0.72	0.05	0.69	-0.11	0.39	-0.1	0.43

Variables	R		FR		RR		D		HD		SD		ED		H		IH		EH		Diet D (months)	
	r	*p*	r	*p*	r	*p*	r	*p*	r	*p*	r	*p*	r	*p*	r	*p*	r	*p*	r	*p*	r	*p*
Muscle mass (kg)	-0.18	0.15	-0.32	0.01 *#	-0.26	0.04 *#	<-0.01	0.99	-0.09	0.48	0.04	0.75	0.01	0.94	-0.07	0.58	-0.05	0.69	0.01	0.29 #	-0.14	0.28
Diet D (months)	-0.15	0.23	-0.04	0.76	-0.14	0.29	-0.21	0.1	-0.27	0.03 *#	0.03	0.8	-0.2	0.11	-0.18	0.15	-0.16	0.22	-0.06	0.63		

R: restraint; FR: flexible restraint; RR: rigid restraint; D: disinhibition; HD: habitual disinhibition; SD: situational disinhibition; ED: emotional disinhibition; H: hunger; IH: internal hunger; EH: external hunger; CHO: carbohydrate; SFA: saturated fat WC: waist circumference; BMI: body mass index (kg/m^2); BFM: body fat mass; Diet D: diet duration.

All correlations were controlled for age, gender and income using partial correlations

*Statistically significant partial correlations (*p* value <0.05) (two-tailed)

#Statistically significant Pearson's correlation prior to controlling for gender and age (*p* value <0.05) (two-tailed)

3.4.6 Regression analyses of TFEQ scores with dietary intake, anthropometry and diet duration

Restraint was the only factor to significantly predict higher CHO (%EI) intake before (B = 0.81, *p* = <0.01) and after (B = 0.74, *p* = <0.01) controlling for gender and age (Table 3.6). With each increase in restraint score, CHO intake (%EI) increased by approximately 0.74%, while the other TFEQ factors, gender and age, were held constant. Restraint predicted lower total fat (%EI) intake (B = -1.06, *p* = <0.01) and SFA (%EI) intake (B = -0.59, *p* = <0.01) significantly (Appendix B1 and B2); however, the overall models were no longer significant once adjusted for gender and age.

Table 3.6

Linear Regression for CHO (%EI) Correlated to Three Factor Eating Questionnaire Factors

Models for CHO (%EI)		B	Std Error B	Standardised β	*p-value*	95% CI
1	(Constant)	4.50	2.95		0.13	-1.39, 10.4
	Restraint	0.81	0.25	0.4	<0.01	0.31, 1.31
	Disinhibition	-0.29	0.4	-0.1	0.47	-1.08, 0.5
	Hunger	0.17	0.47	0.05	0.72	-0.77, 1.11
F= 3.845, R2 adjusted= 0.112, *p-value*= 0.013						
2	(Constant)	9.17	7.2		0.21	-5.22, 23.6
	Restraint	0.74	0.26	0.37	<0.01	0.21, 1.26
	Disinhibition	-0.27	0.4	-0.09	0.51	-1.06, 0.53
	Hunger	0.13	0.49	0.04	0.79	-0.85, 1.12
	Gender	0.56	2.26	0.03	0.8	-3.95, 5.08
	Age	-0.14	0.14	-0.12	0.32	-0.41, 0.14
F= 2.483, R2 adjusted= 0.098, *p-value*= 0.041						

No sub-factors significantly predicted CHO (%EI) before or after controlling for gender and age (Appendix B3). Habitual disinhibition was the only significant sub-factor to predict total fat (%EI) (B = 3.36, *p* = 0.05), however, the overall model lost significance after controlling for age and gender (Appendix B4). As for SFA (%EI), the overall model containing all sub-factors was significant, however, no individual sub-factor was significant (Appendix B5). The model including gender and age was not significant. Protein (%EI) was not predicted by any sub-factor (Appendix B6).

BF% was significantly predicted by restraint before (B = 0.81, p = 0.01) and after (B = 0.6, *p* = 0.03), controlling for gender and age (Table 3.7). Body fat would increase by approximately 0.6% for every point increase in restraint score. Also highlighted in model 2, gender strongly predicted BF% (B = 12.1, *p* = <0.01); on average, females were predicted to have higher BF% than males. No TFEQ factors significantly predicted muscle mass (Appendix B7).

Table 3.7
Linear Regression for BF% Correlated to TFEQ Factors

Models for BF%		B	Std Error B	Standardised β	*p-value*	95% CI
1	**(Constant)**	21	3.58		<0.01	13.9, 28.2
	Restraint	0.81	0.3	0.34	0.01	0.2, 1.41
	Disinhibition	-0.01	0.48	<-0.01	0.99	-0.97, 0.95
	Hunger	-0.98	0.57	-0.22	0.09	-2.12, 0.16
F= 3.086, R2 adjusted= 0.084, *p-value*= 0.033						
2	**(Constant)**	6.13	7.33		0.41	-8.51, 20.8
	Restraint	0.6	0.27	0.25	0.03	0.07, 1.13
	Disinhibition	0.03	0.41	<0.01	0.95	-0.79, 0.84
	Hunger	-0.35	0.5	-0.08	0.49	-1.36, 0.66
	Gender	12.1	2.3	0.54	<0.01	7.52, 16.7
	Age	-0.16	0.14	-0.12	0.27	-0.43, 0.12
F= 8.244, R2 adjusted= 0.348, *p-value*= <0.001						

BF% was significantly inversely predicted by external hunger (B = -4.13, *p* = 0.02); however, after age and gender were considered, gender was the only significant predictor (B = 11.1, *p* = <0.01) (Appendix B8). Both adjusted and unadjusted models containing the sub-factors were significant for predicting muscle mass; however, only gender (B = -12.5, *p* = <0.01) was the significant independent variable in model 2 (Appendix B9).

Diet duration significantly predicted BMI (B = -0.07, p = <0.01) (Appendix B10) and habitual disinhibition (B = -0.02, p = <0.01) (Appendix B11); however, the overall models were no longer significant once gender and age were considered. WC was significantly inversely predicted by diet duration before (B = -0.15, p = <0.01) and after (B = -0.16, p = <0.01), considering gender and age (Appendix B12).

3.5 Discussion

This cross-sectional study investigated the eating behaviours, body compositions, and dietary intakes of free-living, self-reported low-CHO diet users in NZ. Our participants' dietary intake strayed from national recommendations, consuming significantly less CHO (12.5% of EI), greater total fat (58% of EI) and saturated fat (22.6% of EI), but similar protein (24.5% of EI) (Ministry of Health, 2011). For TFEQ scores, participants demonstrated high restraint, low disinhibition, and low hunger, with no significant score differences observed between CHO groups.

3.5.1 Body Composition

Most low-CHO diet users in this study clustered towards the higher end of the normal BMI range (18.50–24.99 kg/m^2), with a median BMI of 24.6 [22.2-28.7] kg/m^2. Their BF% (27.9 ± 9.9%) surpassed the acceptable upper limit for women (25-29%) and exceeded the range for men (20-24%), considering age and gender (Fitch & Bays, 2022). As a low-CHO diet is a popular weight management approach, the overweight individuals within this cohort likely adopted this dietary regimen to mitigate their BMI. The median duration following the diet (9.5 [5-18] months) correlated with lower BMI (r = -0.21, p = 0.03) and WC (r = -0.28, p = 0.03) when age and gender were accounted for, indicating that these self-administered diets successfully facilitated weight management over time. However, meta-analyses have shown that low-CHO diets tend to lose their advanced improvements in BMI and body weight in the long term (approximately >8 months), as control diets or comparison diets show similar results (Dinu et al., 2020; Dong et al., 2020; Naude et al., 2022; Silverii et al., 2022). Therefore, this study's association between BMI and diet duration may only exist in the short term and could diminish as diet duration increases.

No significant differences in body composition measures, including body weight, WC, BMI, BF%, BFM, and muscle mass, were observed between CHO groups. Previous studies linked lower BF% to increased protein consumption in low-CHO groups (Soenen et al., 2012). This may partly explain the absence of BF% disparities between CHO groups in our participants, as they maintained similar protein intakes (%EI). Other studies and systematic reviews consistently emphasise the role of a caloric deficit in achieving weight loss, irrespective of the macronutrient composition of the diet (Bravata et al., 2003; Naude et al., 2022; Sanada et al., 2018). In this study, where all CHO groups were essentially low-CHO, minimal variations in body weight or composition between CHO groups might have been expected. Drastic differences in energy intake may have been necessary to observe body composition disparities between the groups.

3.5.2 Nutrient Intake

The national AMDRs were established to ensure optimal micronutrient intake and mitigate chronic disease risk, suggesting that significant divergence from them could jeopardise nutritional status and health. The AMDR for CHO is 45–65% of total EI, with the population contributing 46-47.1% on average (Ministry of Health, 2011). Our participants exhibited a significantly lower CHO intake, with a mean contribution of CHO to total energy of only 12.5 ± 8.28%. Excessive CHO intake is associated with an increased risk of certain diseases; however, inadequate CHO intake also poses a range of health risks (Oh et al., 2019; Reynolds et al., 2019). Extremely low CHO intake might impact cognitive functioning over time due to the brain's reliance on glucose for energy. When CHO intake is restricted, they are often replaced dietary fat, where the body produces ketones as an alternative fuel (Schutz et al., 2021). While the brain can adapt to ketones, impacts on cognitive function and mental clarity, such as memory impairments, have been observed from low-CHO diets, as the brain may not efficiently utilise fats as its primary energy source (D'Anci et al., 2009). Additionally, the displacement of CHO with dietary fat raises concerns about excess fat accumulation. Unlike CHO, which is readily utilised for energy or stored as glycogen in limited quantities, excess dietary fat is easily stored in adipose tissue, posing the risk of weight gain and obesity-related health issues (Brouns, 2018; Oh et al., 2019).

Complex CHO provides essential dietary fibre for digestive health and disease prevention, which relies on adequate CHO intake. Fibre and whole grain consumption have consistently demonstrated protective effects against various non-communicable diseases, such as CHD, stroke, and diabetes. Fibre intake exhibits a dose-response relationship, with increased consumption linked to reduced body weight, lower blood cholesterol, and improved blood pressure (Reynolds et al., 2019). Soluble fibre, in particular, has demonstrated benefits in reducing blood cholesterol, maintaining stable blood sugar levels, and lowering the risk of cardiovascular issues. The considerably low CHO intake among low-CHO diet users may hinder meeting daily fibre requirements, subsequently exposing them to potential health risks (Brouns, 2018; Ministry of Health, 2011; Reynolds et al., 2019). Therefore, future studies could focus on testing biochemistry to determine the effect of increased %EI of fat and decreased fibre intake from a low-CHO diet.

The protein AMDR, set at 15–25% of total EI, aims to ensure sufficient micronutrient intake for body tissue maintenance and functional protein requirements (Ministry of Health, 2011). The upper limit considers the potential long-term effects of high-protein diets in Western lifestyles, as excessive intake is associated with various chronic diseases such as cancer, renal disease, obesity, CHD and osteoporosis (National Health and Medical Research Council, 2005). Our participants' achieved adequate protein intake that is unlikely to risk their health, with a mean protein intake of 24.5% (23.3-25.9%) of EI. Their protein intakes surpassed the intakes of a group of non-dieting NZ- European women in the EXPLORE study (Schrijvers et al., 2016), yet were similar to other low-CHO dieters reporting intakes of 23.2% (Phelan et al., 2007), 28% (Kakoschke et al., 2021), 20% (Sanada et al., 2018), and >20% of EI (Naude et al., 2022). When CHO are replaced by high protein intakes, protein can be converted into glucose through gluconeogenesis to fuel the brain. However, relying on this is suboptimal as using proteins is metabolically less efficient than using CHO directly, and diverting proteins for energy production may compromise essential bodily functions, such as maintenance of tissue structure, immune function, and enzymatic function (Eberle, 2013).

The AMDR for total fat and SFA is 20–35% and 10% of EI, respectively (Ministry of Health, 2011). In our study, participants showed higher contributions of these respective components at 58.0 ± 11.3% and 22.6 ± 6.98%, exceeding national and EXPLORE study levels (Ministry of Health, 2011; Schrijvers et al., 2016). This deviation, common in low-CHO diets, poses health risks associated with increased fat intake, including breast and ovarian cancer, obesity, CHD, liver disease, and T2DM, all of which the AMDR aims to mitigate while ensuring adequate intake of essential fatty acids (Bravata et al., 2003; Oh et al., 2019). As the present study shows, diets high in total fat are often accompanied by elevated SFA intake, which can raise total and low-density lipoprotein cholesterol levels, subsequently increasing the risk of CHD (Reynolds et al., 2019). It is unfeasible to adopt a diet with no SFA while simultaneously meeting all other nutritional requirements; however, any elevation in SFA intake is associated with unfavourable health impacts, therefore, an upper limit of 10% is recommended (National Health and Medical Research Council, 2005). Evidently, low-CHO diet users are at an elevated risk of health concerns associated with excessive fat intake.

As anticipated, CHO intakes significantly differed among the three groups, with a corresponding decrease in energy intake as CHO intake decreased. This aligns with the theory that low-CHO diets organically result in energy restriction due to their macronutrient composition, promoting appetite suppression, making them appealing for weight loss (Erlanson-Albertsson & Mei, 2005; Oh et al., 2019; Tremblay & Bellisle, 2015). After adjusting for age and gender, the SFA and MUFA intakes (%EI) increased with CHO restriction, while protein intake (%EI) remained similar across CHO groups. This suggests that fat, not protein intake, may predict changes in total EI in low-CHO diets. By comparing four diets (normal-protein, normal-CHO; normal-protein, low-CHO; high-protein, normal-CHO; and high-protein, low-CHO) over 12 months, Soenen et al. (2012) showed that a relatively high protein intake (1.1 vs 0.7 g/kg body weight), not CHO or fat intake, is crucial for successful energy restriction and weight management. This is supported by the hierarchy of satiating power, stating that protein is the most satiating macronutrient, followed by CHO and fat (Tremblay & Bellisle, 2015). Therefore, a high protein intake may decrease total EI and improve adherence, leading to effective weight management (Bravata et al., 2003; Fields et al., 2016; Hu et al., 2016).

3.5.3 Eating Behaviours and their Association to Body Composition and Macronutrient Intakes

Our participants demonstrated high restraint (11 [8-15]), with higher scores compared to previous studies examining dieting and non-dieting women in NZ (Kruger et al., 2016; Shepherd, 2018) and healthy, overweight and obese adults from other countries (Blumfield et al., 2018; Jacob et al., 2023; Papini et al., 2022) (scores of 9 (6,12); 9 (6,12); 8.4 ± 5.0; 7.2 ± 3.8 and 8.13 ± 3.95, respectively). In a cross-sectional study on university students, low-CHO dieters also exhibited high levels of restraint, exceeding those of non-dieters (Colombarolli et al., 2022). Our participants elicit strong cognitive control of eating and weight management, as expected in a group of dieter as the concept originated from investigations into purposeful limitation of food intake (Herman & Polivy, 1975). Unfortunately, high restraint levels have been associated with an increased risk of disordered eating, such as increased binge eating (Colombarolli et al., 2022; Herman & Polivy, 1975). Median scores were low for rigid (3 [3-5]) and flexible (2 [1-4]) restraint, indicating that no one restraint style is dominantly followed within this group, or they have traits and behaviours associated with both sub-factors, e.g. an individual adheres strictly to a structured diet during weekdays (rigid restraint), while they adapt to allow room for treats without guilt on weekends (flexible restraint); these scores did not significantly differ between CHO groups.

The present study's participants showed low disinhibition (5 [3.5,7.5]), with similar scores seen in other studies: 5.6 ± 4.1(Blumfield et al., 2018), 6 (4,9) (Kruger et al., 2016), and 7.48 (3.23) (Papini et al., 2022). Other studies have shown high disinhibition with scores of 8 (5,11) (Shepherd, 2018) and 8.5 ± 3.1 (Jacob et al., 2023). Therefore, this sample of low-CHO diet users is less likely to lose cognitive control over food consumption and give in to food temptations (Bond et al., 2001; Stunkard & Messick, 1985). Low disinhibition is considered the ideal as it is associated with higher sleep quality, healthier eating habits, and improved anthropometric measures such as BF% and BMI (Blumfield et al., 2018; Bryant et al., 2019;

Shepherd, 2018; Shiozawa et al., 2020). It is considered ideal for body composition when combined with high restraint (Lesdéma et al., 2012). Median scores for habitual, situational, and emotional disinhibition were low, indicating a lower likelihood of losing control of eating due to established habits, certain situations, or emotional triggers (Bond et al., 2001). This suggests strong commitment among participants to adhere to their low-CHO diet, potentially influencing their eating behaviours and mitigating susceptibility to external disinhibitory triggers. Disinhibition scores did not significantly differ between the CHO groups, suggesting a similar approach to their diets, like dietary strategies or mindsets, regardless of CHO intake levels. The duration participants adhered to the low-CHO diet may have been too short for significant adaptations in eating behaviours relative to the level of CHO intake to occur. Additionally, the sample size may have been too small to detect subtle variations in eating behaviours within the low-CHO intake spectrum.

Our participants exhibited low hunger (2 [1,3]), aligning with other studies' findings (Blumfield et al., 2018; Kruger et al., 2016; Papini et al., 2022) while differing from others (Jacob et al., 2023; Shepherd, 2018). Notably, our participants were free-living low-CHO diet users who chose this dietary approach, distinguishing it from some studies mentioned involving general, non-dieting populations. According to Stunkard and Messick (1985), low hunger signifies that conventional hunger cues may not be the primary driver of food choices. This suggests that these low-CHO dieters may develop alternative cues or strategies for managing their food intake, such as dietary principles or meal planning to guide their eating decisions. This may also explain their low energy intake, as hunger is associated with energy intake (Leblanc et al., 2012). These low hunger scores may partially result the satiating effect of high protein consumption in low-CHO diets (Oh et al., 2019; Tremblay & Bellisle, 2015). While low hunger is desirable for weight management (Lesdéma et al., 2012), a poor ability to perceive hunger signals may indicate an inability to eat intuitively and mindfully, associated with disordered eating and poor psychological outcomes (Katcher et al., 2021; Linardon et al., 2021). Participants demonstrated low internal (0 [0-1]) and external hunger (1 [0-1]). Their score differences suggest that their food choices were more influenced by external than internal hunger cues, however, these differences were not significant. Hunger scores did not differ significantly between CHO groups.

The absence of significant differences in TFEQ scores for the main factors between the CHO groups suggests that the degree of CHO restriction beyond a moderately low-CHO diet (100-150 g/day) may not impact eating behaviours differently. Further analysis, however, revealed associations between the TFEQ factors and nutrient intakes; CHO (%EI) intake positively related to restraint ($r = 0.34$, $p = <0.01$), suggesting that those who consumed lower CHO proportions had less dietary restraint. Higher restraint scores predicted increased CHO intake (%EI) when age, gender and other TFEQ factors were considered (B = 0.74, p = 0.006). This may be counterintuitive, as one might assume higher levels of restraint are required for heavier dietary restrictions. Lower restraint scores were associated with and significantly predicted increased total fat (%EI) (r = -0.35, p = <0.01) and SFA (%EI) (r = -0.31, p = 0.01), coinciding with CHO intake. One possible explanation is rooted in the philosophy of low-CHO diets, particularly those aligned with ketogenic principles, where fats are often emphasised as a positive diet component. Individuals may perceive that by avoiding CHO, often considered the primary culprit in weight gain and health concerns, they can afford a more liberal approach to dietary fat without the same apprehension. This perspective aligns with the notion that some low-CHO dieters adopt a "fat-friendly" mindset, believing that increased fat consumption is acceptable and potentially beneficial for energy, satiety, and health outcomes (Alharbi & Al-Sowayan, 2020; Fields et al., 2016; Noakes & Windt, 2017).

The TFEQ sub-factor scores also did not differ drastically between CHO groups; however, further analysis revealed significant associations with nutrient intake when considering gender and age. CHO (%EI) intake positively correlated with rigid and flexible restraint, while total and SFA (%EI) intake were inversely associated with rigid and flexible restraint. The similar correlations between rigid and flexible restraint with macronutrients, along with their similar scores, likely stem from the overarching influence of overall restraint. Since overall restraint exhibited similar correlations with CHO, total fat, and SFA, these associations appear to extend to the restraint sub-factors. TFEQ sub-factor scores of low-CHO dieters are a previously unexplored topic; therefore, comparisons cannot be made with previous findings. Protein (%EI) was positively associated with rigid restraint; however, this association lost significance once gender and age were considered. This suggests that individuals with an ‘all-or-nothing’ approach to dietary restraint may have a higher relative protein intake.

Few other studies have explored the effect of low-CHO diets on eating behaviours using the TFEQ. A study involving overweight and obese adults on a four-week low-CHO diet demonstrated a mean 102% increase in restraint, 17% decrease in disinhibition, and 22% decrease in hunger scores (Anguah et al., 2019). Similar effects were observed from a low-CHO diet over one year (Soenen et al., 2012) and in overweight and obese adults with T2DM in a three-month low-CHO diet (Saslow et al., 2014). Unlike studies involving non-low-CHO diet users, these studies demonstrated TFEQ scores comparable to the present study, which reflected this apparent effect of a low-CHO diet to increase restraint and decrease disinhibition and hunger. The Dutch Eating Behaviour Questionnaire is comparable to the TFEQ and has shown that low-CHO diets reduce emotional and external eating, and increase restrained eating (Mohorko et al., 2019). The common effect of a low-CHO diet on eating behaviours might be related to the typically high protein content in these diets, due to its high satiating effect that reduces perceived hunger and the likeliness of disinhibitory behaviours, such as snacking or bingeing, and may promote restraint (Tremblay & Bellisle, 2015). Notably, similar changes in eating behaviours have also been observed in iso-calorically restricted control diets, regardless of the CHO intake level (Cheng et al., 2014; Phelan et al., 2007; Saslow et al., 2014; Soenen et al., 2012), suggesting that these effects may arise from the dieting approach, rather than the specific diet.

Previous studies indicate that the mean duration of self-imposed low-CHO diets was 9.5 months, providing sufficient time for eating behaviour changes to occur (Papini et al., 2022; Soenen et al., 2012). A significant discovery in this study was the negative correlation between diet duration and habitual disinhibition ($r = -0.27$, $p = 0.03$). It suggests individuals adhering to a low-CHO diet for longer periods may exhibit lower susceptibility to habitual disinhibition-related eating behaviours. Possible explanations include the evolution of habits and routines over time when a specific diet is followed or that individuals with low habitual disinhibition adhere to a diet for longer due to better resistance to disruptive old habits. Further research is needed to clarify this correlation between habitual disinhibition and diet duration and whether it is a result of a low-CHO diet, given the limited existing literature.

The only anthropometric measure with a significant correlation to eating behaviours was BF%. Controlling for gender and age, restraint positively correlated to BF% ($r = 0.28$, $p = 0.02$) and even emerged as a significant predictor of BF% ($B = 0.6$, $p = 0.027$). With every additional restraint score, body fat is predicted to increase by 0.6%. This association aligns with other studies investigating eating behaviours and body composition in adults (Beiseigel & Nickols-Richardson, 2004; Chearskul et al., 2010; Drapeau et al., 2003; Hoenink et al., 2023; Pacheco et al., 2021). In contrast, some NZ studies have reported BF% to be negatively associated with restraint and positively associated with disinhibition (Kruger et al., 2016; Shepherd, 2018).

For TFEQ sub-factors, BF% positively correlated with flexible restraint (controlled for age and gender) and rigid restraint (before controlling for gender and age). Conversely, muscle mass exhibited a negative correlation to rigid restraint and flexible restraint, considering age and gender. Given the similar degrees of correlations for restraint sub-factors with BF% and muscle mass, it remains unclear which approach (rigid or flexible) positively or negatively impacts body composition. Rigid restraint may offer short-term benefits by promoting adherence to a specific dietary plan due to its strict “all-or-nothing” mindset, but it is associated with adverse effects, such as an increased susceptibility to overeating in response to perceived lapses in dietary rules. This potentially leads to cycles of strict adherence and subsequent overeating that can increase BF% (Johnson et al., 2012; Westenhoefer et al., 1999). Alternatively, flexible restraint, with its more adaptable and moderate approach, is linked to sustainable positive effects on body composition, such as BF% reduction or muscle mass growth. Flexible restraint promotes informed food choices without the rigidity of strict rules, promoting a healthier relationship with food, however, too much flexibility, may lead to a lack of structure or accountability, overconsumption, and hindered progress toward body composition goals (Johnson et al., 2012; Westenhoefer et al., 1999). The balanced scores in this low-CHO sample may favourably influence body composition, as extreme forms of either sub-factor may pose unique challenges.

BF% correlated positively with habitual disinhibition and negatively with external hunger, while muscle mass correlated positively to external hunger. However, these findings lacked significance when gender and age were considered, which is crucial in body composition variables (Rai et al., 2023). Muscle mass, body weight, BMI, WC, and BFM displayed no significant correlations to TFEQ factors or sub-factors, similar to other studies (Chearskul et al., 2010; Henderson, 2016). The participant group in this study did not adequately represent the general population and had relatively narrow anthropometric ranges. Very few participants had a BMI >30 kg/m^2 and none had a BF% > 30%, thus, potential associations between eating behaviours and anthropometry might have been underestimated. Other studies have observed significant relationships, including BMI positively associated with disinhibition and restraint (Blumfield et al., 2018; Shepherd, 2018), restraint predicting weight loss (Papini et al., 2022), and sub-factors such as emotional disinhibition and external hunger related to BF%, weight, BMI, and WC (Hoenink et al., 2023).

3.5.4 Strengths and Limitations

This study contributes significantly to understanding free-living low-CHO diet users in NZ. Classifying participants into distinct CHO intake groups provides the nuanced exploration of differences in nutrient intakes, eating behaviours, and body composition. Using the validated TFEQ questionnaire added rigour to the study, ensuring the reliability and validity of findings. Limiting food records to four days, obtained comprehensive dietary data while mitigating participant burden. Meticulous dietary data assessment, including adjustments for ingredients or food substitutions, strengthened the estimation of nutrient intake. Limitations include the cross-sectional design which restricts establishing causality, and the small sample size (n=69) with uneven demographic representation challenged broad generalisability. Uneven distribution among CHO groups and reliance on self-reported records introduced potential biases and inaccuracies. The TFEQ's non-exhaustive nature was mitigated using the comprehensive 51-item version, but additional validated tools, such as the Binge Eating Scale (Gormally et al., 1982) or the Intuitive Eating Scale (Tylka, 2006), could have offered a more comprehensive perspective on eating behaviours. These limitations underscore avenues for improvement in future research.

3.6 Conclusion:

This cross-sectional NZ study explores relationships between self-prescribed low-CHO diets, eating behaviours, nutrient intake, and body composition. Low-CHO diet users maintained normal BMI and BF%, with diet duration correlating to lower BMI and WC, reflecting effective weight management outcomes. The degree of CHO restraint did not lead to differences in body composition measures between groups. Macronutrient intakes deviated significantly from recommendations, indicating potential health risks, particularly relating to excessively high fat intakes. Eating behaviour analysis revealed high restraint and low disinhibition and hunger, reflecting strong cognitive control typical of self-directed restrictive dietary practices. Absence of significant TFEQ score differences between CHO groups suggests the degree of CHO restriction may not have distinctly impacted eating behaviours. However, high restraint correlated with increased CHO (%EI) and decreased total fat and SFA (%EI) intakes, predicting higher BF% and indicating potential health risks. Considering dietary intake, body composition, and eating behaviours are essential in evaluating low-CHO diet outcomes, further research, particularly longitudinal studies with a larger NZ population, can provide deeper insights into relationships between low-CHO diets and eating behaviours.

Chapter 4

Conclusions and Recommendations

4.1 Overview and Conclusions

The global rise in obesity poses significant health risks, including the increased likelihood of chronic conditions like type 2 diabetes and cardiovascular diseases. In response, many individuals turn to various dietary practices to manage weight, with the low-CHO diet being a popular choice. However, the absence of a universally accepted definition for low-CHO diets complicates research interpretation, and free-living low-CHO diet users restrict CHO intake to varying degrees. Debates persist about the long-term sustainability, effectiveness of weight management, and safety of low-CHO diets.

Eating behaviours, crucial for understanding individuals' food choices, impact physical and psychological well-being. The Three-Factor Eating Questionnaire (TFEQ) is a validated tool measuring dietary restraint, disinhibition, and hunger, reflecting cognitive control, loss of control, and hunger perception. Eating behaviours can change due to life events, environments, and diets, and they can reciprocally influence dietary choices and adherence. Certain diets, while aiding weight management, may carry risks like psychological stress, disordered eating, and poor sustainability.

Despite the increasing popularity of low-CHO diets, a significant research gap exists, particularly in understanding their relationship with eating behaviours, especially in NZ. A more comprehensive understanding of these interactions can guide dietary recommendations for individuals seeking to adhere to a low-CHO diet. This study investigated the differences in eating behaviours and body composition among different CHO intake categories of free-living, self-reported low-CHO diet users. A four-day food record, anthropometric measurements, and TFEQ scores were collected from 69 participants to fulfil this aim. To our knowledge, this is the first study which has assessed the eating behaviours of free-living low-CHO diet users in NZ.

The first objective of the present study was to assess the body compositions of low-CHO diet users overall and by level of CHO intake. Body composition was assessed for the total study group and the CHO groups with different levels of CHO intake restriction using ANCOVA, Quade's tests, Tukey post-hoc tests, and Bonferroni corrections. These dieters overall had a mean BF% of 27.9 ± 9.9%, a median body fat mass of 18.9 [13.3-27.3] kg, and a median muscle mass of 28.0 [25.2-33.2] kg. It was hypothesised (1) that as CHO intake decreased, body fat would decrease while muscle mass would increase, however, these measures did not differ between the CHO intake groups (Table 3.2), therefore hypothesis 1 is rejected. These findings suggest that the level of CHO restriction within a low-CHO diet may not impact body composition significantly. However, due to the cross-sectional study design, a causal relationships cannot be definitively established.

The second objective was to assess the dietary intake of low-CHO diet users overall and by level of CHO intake. Hypothesis 2, proposing significant variations in CHO and fat but not protein intake among dieters, was confirmed. The CHO intakes differed significantly between the CHO groups based on absolute (g/day); $p = <0.001$) and relative (%EI; $p = <0.001$) measures. Furthermore, significantly higher total and saturated fat intakes (%EI) were observed in the lowest CHO group than in the higher CHO groups. Protein (%EI) did not differ with the level of CHO intake (Table 3.2), showing that these dieters tended to substitute CHO with fat over protein intakes. Therefore, hypothesis 2 can be accepted.

The third objective was to assess the eating behaviours (restraint, hunger and disinhibition and their various sub-factors using the TFEQ) of low-CHO diet users overall and by level of CHO intake, using ANCOVA analysis adjusted for gender and age. As hypothesised (3.1), this cohort had high restraint, meaning they had strong cognitive control (11 [8-15]) of eating and weight management. Therefore, the first part of hypothesis 3.1 can be accepted. Restraint sub-factors showed low rigid (3 [3-5]) and flexible (2 [1-4]) restraint, suggesting that no one restraint style was dominantly followed within this group, or they may have demonstrated a combination of the two sub-factors. Restraint scores were not higher in the lower CHO groups; thus, the second part of hypothesis 3.1, stating that restraint would increase with each decreasing CHO intake group, is rejected.

We hypothesised (3.2) that the cohort would show low disinhibition and that disinhibition would increase with each lower CHO intake group. This cohort had low disinhibition (5 [3.5,7.5]) overall, meaning they were less likely to lose cognitive control over food consumption and give in to food temptations. Therefore, the first part of hypothesis 3.2 is accepted. Habitual, situational, and emotional disinhibition scores were low, meaning they were less prone to lose control over their eating due to established habits, specific situations, or emotional triggers. The degree of CHO restriction did not appear to impact the level of disinhibition, as disinhibition scores did not differ between CHO groups, thus the second part of hypothesis 3.2 is rejected.

It was also hypothesised (3.3) that this low-CHO cohort would have low hunger scores and that hunger would increase with each lower CHO intake group. They displayed low hunger with a median score of 2 [1,3], suggesting that traditional hunger signals may not primarily guide their food choices. Individuals on low-CHO diets might rely on alternative cues or strategies, such as dietary principles or meal planning, for managing their food intake. As hunger was low, the first part of hypothesis 3.3 can be accepted. For the hunger sub-factors, lower susceptibility to internal and external hunger cues were found. Hunger scores were not different between CHO groups, meaning the variance in CHO intakes in this group did not impact hunger scores or was not drastic enough to cause score differences. Consequently, the second part of hypothesis 3.3 is rejected.

This study's fourth objective was to explore the relationships between body composition, macronutrient intake, eating behaviour, and diet duration in low-CHO diet users. Partial correlations were performed to control for gender and age (Table 3.5). It was predicted (4.1) that restraint would increase as CHO intake decreased. The CHO (%EI) intake was positively related to restraint, suggesting that those who consumed fewer CHO had less cognitive control with eating. Higher restraint scores were even found to predict increased CHO intake (%EI) using linear regression analysis controlling for age, gender and other TFEQ factors (Table 3.6). Therefore, hypothesis 4.1 is rejected. Further associations were found as lower restraint scores predicted an increase in total fat (%EI), possibly due to the emphasis on unrestrained fat intake as a core aspect of a low-CHO diet. Individuals with higher CHO intake (%EI) and lower total and SFA intake (%EI) showed higher rigid and flexible restraint. Another discovery was the negative association between diet duration and habitual disinhibition, implying that a low-CHO diet may lessen the impact of habits on diet disruption over time.

It was hypothesised (4.2) that high restraint, low hunger, and low disinhibition scores would be associated with more favourable body composition measures (i.e., lower body fat and higher muscle mass). The BF% was the only body composition measure to correlate with TFEQ scores. As BF% increased, restraint increased, and with every additional restraint score, body fat was predicted to increase by 0.6% (Table 3.7). Due to this and the fact that disinhibition and hunger did not correlate to body composition, hypothesis 4.2 is rejected. As for TFEQ sub-factors, BF% was positively associated with flexible restraint, while muscle mass was negatively associated with flexible and rigid restraint. As findings for flexible and rigid restraint were similar, it is unclear which benefits body composition. Additionally, BMI was negatively correlated with diet duration, alluding to the diet’s success as a weight management approach.

4.2 Strengths and limitations of the research

Strengths:

This study presents several strengths in understanding free-living low-CHO diet users and their association with eating behaviours, nutrient intakes, and body composition in NZ. One notable strength was using free-living diet users as the study population. Unlike studies with prescribed diets that may not reflect real-world applications (Anguah et al., 2019; Mohorko et al., 2019; Saslow et al., 2014), this approach offered a genuine perspective on how individuals authentically adopt and apply low-CHO diets in their daily lives. The classification of participants into three distinct CHO intake groups was another noteworthy strength as it enabled the exploration of differences in dietary intakes, eating behaviours, and body composition across the three groups, providing an advanced understanding of CHO restriction and its associations with behaviour and health. Using a validated questionnaire (the TFEQ) to measure eating behaviours added rigour to the study. This tool, widely recognised in research, enhanced the reliability and validity of the findings.

Furthermore, the study's decision to limit food records to four days created a balance between obtaining comprehensive dietary data and mitigating participant burden, leading to optimal accuracy (Stram et al., 1995). Dietary data assessment was highly detailed and incorporated appropriate adjustments for ingredients or food substitutions when necessary to strengthen the estimation of nutrient intake. Only three prior studies have investigated eating behaviours in NZ using the TFEQ (Brown et al., 2014; Kruger et al., 2016; Shepherd, 2018). Brown et al. (2014) examined eating behaviours in average-weight and overweight men and women. However, they did not examine BF % nor the sub-factors of the TFEQ. Kruger et al. (2016) assessed BMI and BF % in healthy women, and Shepherd (2018) examined the ethnic differences in eating behaviours in healthy women. However, none of these studies specifically focused on individuals following a specific diet, particularly a low-CHO diet. This study stands out as the first to analyse the TFEQ factors and sub-factors of free-living low-CHO diet uses in NZ, shedding light on the relationship between their dietary behaviours and various health parameters.

Limitations:

While this study provides valuable insights into self-prescribed low-CHO diets, it is essential to acknowledge its limitations. The cross-sectional study design is a primary constraint, preventing causality or directionality in the observed correlations. The present sub-study had a small sample size (n=69), meaning the findings are not broadly generalisable, especially considering the uneven distribution across ethnicities (mostly NZ-European) and genders (predominantly females). The overrepresentation of individuals with higher education, as a result of recruiting from university students, further limited the diversity of the sample. Additionally, the uneven distribution among CHO groups and the reliance on self-reported food records introduced potential biases (under-reporting and social desirability) and inaccuracies. Food records had room for error due to inaccurate reporting, and their assessment can be limited by NZ food databases not containing all accurate food items. The use of the TFEQ is not exhaustive for assessing eating behaviours. However, the most comprehensive 51-item version was used (Bond et al., 2001) as opposed to shortened versions (TFEQ-18) (Karlsson et al., 2000). Including additional validated tools, such as the Binge Eating Scale (Gormally et al., 1982) or the Intuitive Eating Scale (Tylka, 2006), could have provided a more holistic view of eating behaviours. The recently published New Zealand Eating Behaviour Questionnaire (Schmiedel et al., 2023) uses a unique factor structure and presentation that has been validated within the NZ context. Future employment of this questionnaire may increase the generalisability of this study's findings to an NZ population. While the study adjusted for gender and age, it did not adjust for other potential confounding factors like income or ethnicity. Physical activity and history of obesity or overweight were potential confounding variables of eating behaviours that were not assessed. These limitations suggest directions for improvement in future research endeavours.

4.3 Recommendations for future research

- To include a larger sample size reflective of the NZ population in terms of gender, age, educational background, and ethnicity to enhance the generalisability of findings.
- To include additional eating behaviour measures such as the Intuitive Eating Scale, the Binge Eating Scale, and the NZ Eating Behaviour Questionnaire.
- To investigate psychological factors influencing eating behaviours, such as stress, emotional well-being, and cognitive patterns, to further explain the psychological impacts of low-CHO diets.
- To investigate the biomarkers of metabolic diseases and their association with eating behaviours in low-CHO diet users.
- Conduct longitudinal studies to explore changes in eating behaviours, body composition, and nutrient intakes over an extended period among low-CHO diet users.
- To conduct a randomise-controlled trial that prescribes participants to a control diet, a low-, moderately low-, or very low-CHO diet, or a high-CHO low-fat diet to investigate how eating behaviours are impacted depending on the level of CHO intake and how different baseline behaviours may impact adherence to the diet.

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Appendix

Appendix A. *Supplementary Methods*

Appendix A1. *Health and Demographics Questionnaire of the LOCA study*

The LOCA Study Health and Demographics Questionnaire

1. Please enter your study ID (if you are not sure, please ask the researcher)

2. Please enter your first name

3. What is your first language?

- English
- Other (please specify)

4. What is the highest level of education you have received?

- Primary School
- Secondary School (College, e.g. school certificate / bursary / NCEA Level 1-3)
- Trade Certificate or Diploma
- University or other Tertiary Education (e.g. Post Graduate Diploma and Certificate, Bachelor's Degree, Masters Degree, PhD

Other (please specify)

5. To which ethnic group do you belong? Choose whichever applies to you, you make choose more than one.

- New Zealand European
- Maori
- Samoan
- Cook Island Maori
- Tongan
- Niuean
- Chinese
- Indian
- Other (please specify)

1

6. If you chose more than one ethnicity, please state the ethnicity you most identify with first and foremost.

7. Which country were you born in?

- [ ] New Zealand
- [ ] Australia
- [ ] People's Republic of China
- [ ] Scotland
- [ ] South Africa
- [ ] Cook Islands
- [ ] Samoa
- [ ] Other (please specify)

8. If you live in New Zealand, but were not born here, when did you first arrive to live in New Zealand?

Date/Month/Year

DD/MM/YYYY

9. What is your date of birth?

Date/Month/Year

DD/MM/YYYY

10. What is your marital status?

- [ ] Single
- [ ] Partner / de facto / married
- [ ] Other

11. What is your living arrangement?

- ◯ Live alone
- ◯ Live with family
- ◯ Flatting
- ◯ Live with a partner

12. What is your working status?

- ☐ Paid employment
- ☐ Retired
- ☐ Stay at home parent/caregiver
- ☐ Unemployed
- ☐ Student
- ☐ Disability Allowance
- ☐ Beneficiary

13. In your current paid employment:

What is your occupation (e.g. nurse, accountant, teacher)	
Please enter the dates worked	
Please enter the main activity of the company/organisation	

14. In your previous paid employment:

What was your occupation	
Please enter the dates worked	
Please enter the main activity of the company/organisation	

15. What would be the total income that the household received from all sources before tax has been taken out in the past 12 months?

- [ ] Loss
- [ ] Zero
- [ ] $1-$5,000
- [ ] $5,001-$10,000
- [ ] $10,001-$15,000
- [ ] $15,001-$20,000
- [ ] $20,001-$30,000
- [ ] $30,001-$40,000
- [ ] $40,001-$50,000
- [ ] $50,001-$70,000
- [ ] $70,001-$100,000
- [ ] $100,000 or more
- [ ] I don't want to answer

16. How many hours do you usually work each day?

17. How many hours do you usually work each week?

18. What is your usual work pattern in your current paid work?
Please tick the box that best applies

- [ ] Daytime with no shifts
- [ ] Rotating shifts with nights
- [ ] Rotating shifts without nights
- [ ] Permanent nights
- [ ] Irregular or variable
- [ ] Other (please specify)

19. If you work night shifts, how many do you work in a usual week?

20. Do you follow any dietary restrictions for cultural or religious reasons?

- ◯ No
- ◯ Yes (please explain)

21. At what speed do you eat your meals?

- ◯ Quickly
- ◯ At a moderate pace
- ◯ Slowly

22. When did your last menstrual period start?

Date

DD/MM/YYYY

23. Are you pregnant?

- ◯ Yes
- ◯ No

24. Do you smoke cigarettes?

- ◯ Non-smoker
- ◯ Former smoker
- ◯ Current (approximately how many cigarettes per day?)

25. Do you drink alcohol?

- [ ] Never or very rarely
- [ ] One drink per week
- [ ] More than one drink per week
- [ ] One drink per day
- [ ] More than one drink per day

26. Do you have any diagnosed allergies?

- ○ No
- ○ Yes (please specify)

27. Are you taking any form of medication, including traditional or homeopathic medicine and contraception?

- ○ Yes
- ○ No

28. If yes, please specify the condition, medication, dosage and frequency below.

Condition 1	
Medication 1	
Dosage 1	
Frequency 1	
Condition 2	
Medication 2	
Dosage 2	
Frequency 2	
(continue here if further medication)	

29. Are you taking any form of supplements, including tablets or drinks?

- ○ Yes
- ○ No

30. If yes, please tell us the name, brand, dosage and frequency of the supplements you are taking below.

Supplement 1 [ ]

Brand 1 [ ]

Dosage 1 [ ]

Frequency 1 [ ]

Supplement 2 [ ]

Brand 2 [ ]

Dosage 2 [ ]

Frequeny 2 [ ]

(continue here if further supplements) [ ]

31. Please tell us how you found out about this study.
Did you find out from:

- [ ] A friend?
- [ ] Social media?
- [ ] An email list?
- [ ] Flyer on noticeboard?
- [ ] Other (please specify)

[ ]

32. Please tell us which social media page / event / where the flyer was / which email list you found out about our study from

[ ]

33. Would you like to receive a brief report summarising the main findings of the project?

○ Yes

○ No

34. Are you willing to be contacted regarding future research projects within the School of Sport, Exercise and Nutrition? Your name and email address will be saved in a secure location. You will be sent periodic newsletters regarding research studies within the School. You can opt out of this newsletter at any time.

☐ Tick this box if you accept

☐ No

Appendix A2. *The Three-Factor Eating Questionnaire (from Stunkard and Messick (1985))*

The LOCA Study Eating Behaviour Questionnaire

The LOCA Study Eating Behaviour Questionnaire

* 1. Please enter your study ID (if you are not sure please ask the researcher)

Study identification number

2. Please enter your first name

1

The LOCA Study Eating Behaviour Questionnaire

Please answer each question by choosing the the appropriate answer (True or False)

3. 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

- True
- False

4. I usually eat too much at social occasions, like parties and picnics

- True
- False

5. I am usually so hungry that I eat more than three times a day

- True
- False

6. When I have eaten my quota of calories, I am usually good about not eating any more

- True
- False

7. Dieting is so hard for me because I just get too hungry

- True
- False

8. I deliberately take small helpings as a means of controlling my weight

- True
- False

9. Sometimes things just taste so good that I keep on eating even when I am no longer hungry

- True
- False

10. Since I am often hungry, I sometimes wish that while eating, an expert would tell me that I have had enough or that I can have something more to eat

- ◯ True
- ◯ False

11. When I feel anxious, I find myself eating

- ◯ True
- ◯ False

12. Life is too short to worry about dieting

- ◯ True
- ◯ False

13. Since my weight goes up and down, I have gone on reducing diets more than once

- ◯ True
- ◯ False

14. I often feel so hungry that I just have to eat someting

- ◯ True
- ◯ False

15. When I am with someone who is overeating, I usually overeat too

- ◯ True
- ◯ False

16. I have a pretty good idea of the number of calories in common food

- ◯ True
- ◯ False

17. Sometimes when I start eating, I just can't seem to stop

- ◯ True
- ◯ False

18. It is not difficult for me to leave something on my plate

- True
- False

19. At certain times of the day, I get hungry because I have gotten used to eating someting then

- True
- False

20. 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

- True
- False

21. Being with someone who is eating often makes me hungry enough to eat also

- True
- False

22. When I feel blue, I often overeat

- True
- False

23. I enjoy eating too much to spoil it by counting calories or watching my weight

- True
- False

24. When I see a real delicacy, I often get so hungry that I have to eat right away

- True
- False

25. I often stop eating when I am not really full as a conscious means of limiting the amount that I eat

- True
- False

26. I get so hungry that my stomach often seems like a bottomless pit

- ◯ True
- ◯ False

27. My weight has hardly changed at all in the last ten years

- ◯ True
- ◯ False

28. I am always hungry so it is hard for me to stop eating before I finish the food on my plate

- ◯ True
- ◯ False

29. When I feel lonely, I console myself by eating

- ◯ True
- ◯ False

30. I consciously hold back at meals in order not to gain weight

- ◯ True
- ◯ False

31. I sometimes get very hungry late in the evening or at night

- ◯ True
- ◯ False

32. I eat anything I want, any time I want

- ◯ True
- ◯ False

33. Without even thinking about it, I take a long time to eat

- ◯ True
- ◯ False

34. I count calories as a conscious means of controlling my weight

- ◯ True
- ◯ False

35. I do not eat some foods because they make me fat

- ◯ True
- ◯ False

36. I am always hungry enough to eat at any time

- ◯ True
- ◯ False

37. I pay a great deal of attention to changes in my figure

- ◯ True
- ◯ False

38. While on a diet, if I eat a food that is not allowed, I often then splurge and eat other high calorie foods

- ◯ True
- ◯ False

The LOCA Study Eating Behaviour Questionnaire

Please answer the following questions by choosing the response that is appropriate to you.

39. How often are you dieting in a conscious effort to control your weight?

- ◯ Rarely
- ◯ Sometimes
- ◯ Usually
- ◯ Always

40. Would a weight fluctuation of 2.5 kg (5 lbs) affect the way you live your life?

- ◯ Not at all
- ◯ Slightly
- ◯ Moderately
- ◯ Very much

41. How often do you feel hungry?

- ◯ Only at mealtimes
- ◯ Sometimes between meals
- ◯ Often between meals
- ◯ Almost always

42. Do your feelings of guilt about overeating help you to control your food intake?

- ◯ Never
- ◯ Rarely
- ◯ Often
- ◯ Always

43. How difficult would it be for you to stop eating halfway through dinner and not eat for the next four hours?

- Easy
- Slightly difficult
- Moderately difficult
- Very difficult

44. How conscious are you of what you are eating?

- Not at all
- Slightly
- Moderately
- Exremely

45. How frequently do you avoid ‘stocking up’ on tempting foods?

- Almost never
- Seldom
- Usually
- Almost always

46. How likely are you to shop for low calorie foods?

- Unlikely
- Slightly likely
- Moderately likely
- Very likely

47. Do you eat sensibly in front of others and splurge alone?

- Never
- Rarely
- Often
- Always

48. How likely are you to consciously eat slowly in order to cut down on how much you eat?

- ◯ Unlikely
- ◯ Slightly likely
- ◯ Moderately likely
- ◯ Very Likely

49. How frequently do you skip dessert because you are no longer hungry?

- ◯ Almost never
- ◯ Seldom
- ◯ At least once a week
- ◯ Almost every day

50. How likely are you to consciously eat less than you want?

- ◯ Unlikely
- ◯ Slightly likely
- ◯ Moderately likely
- ◯ Very likely

51. Do you go on eating binges though you are not hungry?

- ◯ Never
- ◯ Rarely
- ◯ Sometimes
- ◯ At least once a week

52. 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?. Choose the answer which best describes you.

- ◯ 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’

53. To what extent does this statement describe your eating behaviour ?
‘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.’

- ◯ Not like me
- ◯ A little like me
- ◯ Pretty good description of me
- ◯ Describes me perfectly

Appendix A3. *General Coding of the Three-Factor Eating Questionnaire*

Factor/sub-factor	Number of questions	Examples of question number items
Total restraint	21	**4, 6,** 10, **14, 18,** 21, 23, **28,** 30, **32**, 33, **35, 37, 38, 40, 42, 43, 44,** 46, **48**, 50
Flexible restraint	7	4, 6, 18, 28, 35, 42, 48
Rigid restraint	7	14, 32, 37, 38, 40, 43, 44
Total disinhibition	16	1**, 2, 7, 9, 11, 13, 15, 16, 20,** 25, **27,** 31**, 36, 45, 49, 51**
Habitual disinhibition	5	11, 36, 45, 49, 51
Emotional disinhibition	3	9, 20, 27
Situational disinhibition	5	2, 7, 13, 15, 16
Total hunger	14	**3, 5, 8, 12,** 17**, 19, 22, 24, 26,** 29**, 34, 39, 41, 47**
Internal hunger	6	3, 5, 12, 24, 34, 39
External hunger	6	8, 19, 22, 26, 41, 47

Bold examples = the question contributes to a main category AND a sub-category (e.g. R0 AND R1 or 2).
Un-bolded examples = the question only contributes to a main category and NOT a sub-category

Appendix A4. *Part 1 Coding Sheet for the Three Factor Eating Questionnaire*

Question	Score		Factor Number
	True	False	
1	1	0	2
2	1	0	2
3	1	0	3
4	1	0	1
5	1	0	3
6	1	0	1
7	1	0	2
8	1	0	3
9	1	0	2
10	0	1	1
11	1	0	2
12	1	0	3
13	1	0	2
14	1	0	1
15	1	0	2
16	0	1	2
17	1	0	3
18	1	0	1
19	1	0	3
20	1	0	2
21	0	1	1
22	1	0	3
23	1	0	1
24	1	0	3
25	0	1	2
26	1	0	3
27	1	0	2
28	1	0	1
29	1	0	3
30	0	1	1
31	0	1	2
32	1	0	1
33	1	0	1
34	1	0	3
35	1	0	1
36	1	0	2

Factor number 1 = Restraint, 2= Disinhibition, 3 = Hunger.

Appendix A5. *Part 2 Coding Sheet for the Three Factor Eating Questionnaire*

Question	Score		Factor Number
	1 or 2	3 or 4	
37	0	1	1
38	0	1	1
39	0	1	3
40	0	1	1
41	0	1	3
42	0	1	1
43	0	1	1
44	0	1	1
45	0	1	2
46	0	1	1
47	1	0	3
48	0	1	1
49	0	1	2
50	0	1	1
51	0	1	2

Score 1 or 2 = First or second answer choice. Score 3 or 4 = Third or fourth answer choice. Factor number 1 = Restraint, 2= Disinhibition, 3 = Hunger.

The following appendices are available on request:

- Table A6 Assumptions for entering the food records into FoodWorks
- Table A7 Cooking yields
- Table A8 Dietary Assumptions
- Table A9 Items excluded from the dietary analysis

Appendix B. *Supplementary Results*

Appendix B1. *Multiple Linear Regression for Total fat (%EI) Correlated to Main EB Factors*

Models for Fat %EI		**B**	**Std Error B**	**Standardised β**	***p-value***	**95% CI**
1	**(Constant)**	69.7	4.04		<0.01	61.6, 77.7
	Restraint	-1.06	0.34	-0.39	<0.01	-1.74, -0.38
	Disinhibition	0.19	0.54	0.05	0.73	-0.89, 1.27
	Hunger	-0.29	0.64	-0.06	0.68	-1.57, 1
F= 3.783, R2 adjusted= 0.109, *p-value*= 0.015						
2	**(Constant)**	65.5	9.91		<0.01	45.7, 85.3
	Restraint	-0.99	0.36	-0.36	<0.01	-1.71, -0.28
	Disinhibition	0.17	0.55	0.04	0.76	-0.93, 1.27
	Hunger	-0.25	0.68	-0.05	0.72	-1.61, 1.11
	Gender	-0.38	3.11	-0.15	0.9	-6.59, 5.83
	Age	0.12	0.19	0.08	0.53	-0.26, 0.49
F= 2.294, R2 adjusted= 0.087, *p-value*= 0.056						

Appendix B2. *Multiple Linear Regression for SFA (%EI) Correlated to Main EB Factors*

Models for SFA %EI		B	Std Error B	Standardised β	*p-value*	95% CI
1	**(Constant)**	29.3	2.53		<0.01	24.3, 34.4
	Restraint	-0.59	0.21	-0.35	<0.01	-1.01, -0.16
	Disinhibition	-0.04	0.34	-0.02	0.91	-0.72, 0.64
	Hunger	0.06	0.4	0.02	0.87	-0.74, 0.87
F= 3, R2 adjusted= 0.081, *p-value*= 0.037						
2	**(Constant)**	28	6.19		<0.01	15.6, 40.3
	Restraint	-0.54	0.23	-0.32	0.02	-0.99, -0.09
	Disinhibition	-0.05	0.34	-0.02	0.88	-0.74, 0.63
	Hunger	0.04	0.43	0.01	0.92	-0.81, 0.89
	Gender	-1.05	1.94	-0.07	0.59	-4.93, 2.83
	Age	0.08	0.12	0.08	0.51	-0.16, 0.31
F= 1.9, R2 adjusted= 0.062 *p-value*= 0.107						

Appendix B3. *Multiple Linear regression for CHO (%EI) Correlated to TFEQ Sub-Factors*

Models for CHO %EI		B	Std Error B	Standardised β	*p-value*	95% CI
1	(Constant)	5.31	2.74		0.06	-0.18, 10.8
	Rigid Restraint	0.59	0.9	0.13	0.51	-1.21, 2.39
	Flexible Restraint	1.76	0.99	0.33	0.08	-0.22, 3.74
	Habitual Disinhibition	-0.97	1.25	-0.11	0.44	-3.47, 1.53
	Emotional Disinhibition	-0.03	1.01	<-0.01	0.98	-2.05, 1.99
	Situational Disinhibition	-0.37	0.96	-0.06	0.7	-2.29, 1.55
	Internal Hunger	-0.57	1.12	-0.08	0.61	-2.8, 1.67
	External Hunger	1.4	1.52	0.16	0.36	-1.63, 4.43
F= 1.71, R2 adjusted= 0.068, *p-value*= 0.123						
2	(Constant)	10.8	7.37		0.15	-3.93, 25.6
	Rigid Restraint	0.3	0.92	0.07	0.75	-1.53, 2.13
	Flexible Restraint	1.87	0.99	0.35	0.06	-0.11, 3.86
	Habitual Disinhibition	-1.05	1.26	-0.12	0.41	-3.56, 1.46
	Emotional Disinhibition	0.31	1.05	0.04	0.76	-1.79, 2.41
	Situational Disinhibition	-0.63	0.99	-0.1	0.53	-2.61, 1.34
	Internal Hunger	-0.76	1.12	-0.1	0.5	-3, 1.49
	External Hunger	1.79	1.58	-0.21	0.26	-1.36, 4.95
	Gender	1.32	2.46	0.07	0.59	-3.6, 6.25
	Age	-0.21	0.14	-0.19	0.14	-0.5, 0.07
F= 1.6, R2 adjusted= 0.074, *p-value*= 0.135						

Appendix B4. *Multiple Linear regression for Total Fat (%EI) Correlated to TFEQ Sub-Factors*

Models for Total Fat %EI		B	Std Error B	Standardised β	*p-value*	95% CI
1	**(Constant)**	68.3	3.65		<0.01	61, 75.6
	Rigid Restraint	-1.44	1.2	-0.23	0.23	-3.83, 0.95
	Flexible Restraint	-1.91	1.32	-0.26	0.15	-4.55, 0.73
	Habitual Disinhibition	3.36	1.67	0.29	0.05	0.03, 6.69
	Emotional Disinhibition	-0.97	1.35	-0.09	0.47	-3.66, 1.72
	Situational Disinhibition	-0.47	1.28	-0.06	0.72	-3.02, 2.09
	Internal Hunger	0.35	1.49	0.03	0.82	-2.63, 3.32
	External Hunger	-1.32	2.02	-0.11	0.51	-5.35, 2.71
F= 2.278, R2 adjusted= 0.116, *p-value*= 0.04						
2	**(Constant)**	63.5	9.9		<0.01	43.8, 83.3
	Rigid Restraint	-1.14	1.23	-0.18	0.36	-3.59, 1.32
	Flexible Restraint	-2.03	1.33	-0.28	0.13	-4.69, 0.63
	Habitual Disinhibition	3.47	1.68	0.3	0.04	0.1, 6.84
	Emotional Disinhibition	-1.29	1.41	-0.12	0.36	-4.11, 1.52
	Situational Disinhibition	-0.23	1.33	-0.03	0.86	-2.88, 2.42
	Internal Hunger	0.54	1.5	0.05	0.72	-2.47, 3.55
	External Hunger	-1.79	2.11	-0.15	0.4	-6.02, 2.44
	Gender	-1.75	3.3	-0.07	0.6	-8.35, 4.86
	Age	0.21	0.19	0.14	0.27	-0.17, 0.6
F= 1.915, R2 adjusted= 0.108, *p-value*= 0.067						

Appendix B5. *Multiple Linear Regression for SFA (%EI) Correlated to TFEQ Sub-Factors*

Models for SFA %EI		B	Std Error B	Standardised β	*p-value*	95% CI
1	**(Constant)**	28.7	2.25		<0.01	24.2, 33.2
	Rigid Restraint	-0.94	0.74	-0.24	0.21	-2.41, 0.54
	Flexible Restraint	-1.15	0.81	-0.26	0.16	-2.78, 0.48
	Habitual Disinhibition	1.51	1.03	0.21	0.15	-0.54, 3.57
	Emotional Disinhibition	-1.15	0.83	-0.18	0.17	-2.81, 0.51
	Situational Disinhibition	0.26	0.79	0.05	0.74	-1.32, 1.84
	Internal Hunger	0.6	0.92	0.1	0.52	-1.24, 2.43
	External Hunger	-0.83	1.24	-0.14	0.51	-3.32, 1.66
F= 2.253, R2 adjusted= 0.114, *p-value*= 0.042						
2	**(Constant)**	25.6	6.09		<0.01	13.4, 37.8
	Rigid Restraint	-0.72	0.76	-0.19	0.34	-2.23, 0.79
	Flexible Restraint	-1.23	0.82	-0.27	0.14	-2.87, 0.4
	Habitual Disinhibition	1.59	1.04	0.22	0.13	-0.48, 3.66
	Emotional Disinhibition	-1.37	0.87	-0.21	0.12	-3.1, 0.36
	Situational Disinhibition	0.42	0.82	0.08	0.61	-1.21, 2.05
	Internal Hunger	0.74	0.93	0.12	0.43	-1.11, 2.59
	External Hunger	-1.17	1.3	-0.16	0.37	-3.77, 1.43
	Gender	-1.29	2.03	-0.08	0.53	-5.35, 2.78
	Age	0.15	0.12	0.16	0.22	-0.09, 0.38
F= 1.951, R2 adjusted= 0.112, *p-value*= 0.062						

Appendix B6. *Multiple Linear Regression for Protein (%EI) Correlated to TFEQ Sub-Factors*

Models for Protein %EI		**B**	**Std Error B**	**Standardised β**	***p-value***	**95% CI**
1	**(Constant)**	23.9	1.99		<0.01	19.9, 27.8
	Rigid Restraint	1.58	0.65	0.47	0.02	0.28, 2.88
	Flexible Restraint	-0.65	0.72	-0.17	0.37	-2.09, 0.79
	Habitual Disinhibition	-1.95	0.91	-0.32	0.04	-3.76, -0.14
	Emotional Disinhibition	-0.08	0.73	-0.01	0.91	-1.54, 1.39
	Situational Disinhibition	0.5	0.69	0.11	0.47	-0.89, 1.89
	Internal Hunger	-0.04	0.81	<-0.01	0.96	-1.65, 1.58
	External Hunger	0.56	1.1	0.09	0.61	-1.64, 2.75
F= 1.66, R2 adjusted= -0.064, *p-value*= 0.136						
2	**(Constant)**	24	5.44		<0.01	13.1, 34.9
	Rigid Restraint	1.53	0.68	0.46	0.03	0.17, 2.88
	Flexible Restraint	-0.62	0.73	-0.16	0.4	-2.08, 0.84
	Habitual Disinhibition	-1.99	0.93	-0.32	0.04	-3.84, -0.14
	Emotional Disinhibition	-0.05	0.77	<-0.01	0.95	-1.59, 1.5
	Situational Disinhibition	0.48	0.73	0.11	0.51	-0.97, 1.94
	Internal Hunger	-0.07	0.83	-0.01	0.93	-1.73, 1.58
	External Hunger	0.68	1.16	0.11	0.56	-1.64, 3
	Gender	0.57	1.81	0.04	0.75	-3.06, 4.2
	Age	-0.03	0.11	-0.04	0.77	-0.24, 0.18
F= 1.272, R2 adjusted= 0.035, *p-value*= 0.271						

Appendix B7. *Multiple Linear Regression for Muscle Mass Correlating to TFEQ Factors*

Models for Muscle mass		**B**	**Std Error B**	**Standardised β**	***p-value***	**95% CI**
1	**(Constant)**	32.2	2.79		<0.01	26.7, 37.8
	Restraint	-0.42	0.24	-0.23	0.08	-0.88, 0.06
	Disinhibition	0.23	0.37	0.09	0.54	-0.52, 0.98
	Hunger	0.55	0.44	0.16	0.22	-0.34, 1.44
F= 1.5, R2 adjusted= 0.021, *p-value*= 0.224						
2	**(Constant)**	54.4	4.44		<0.01	45.5, 63.3
	Restraint	-0.27	0.16	-0.15	0.1	-0.59, 0.05
	Disinhibition	0.22	0.25	0.08	0.38	-0.27, 0.71
	Hunger	-0.2	0.31	-0.06	0.51	-0.81, 0.41
	Gender	-12.9	1.39	-0.77	<0.01	-15.8, -10.2
	Age	0.02	0.08	0.02	0.86	-0.15, 0.18
F= 19.5, R2 adjusted= 0.577, *p-value*= <0.001						

Appendix B8. *Multiple Linear Regression for BF% Correlating to TFEQ Sub-Factors*

Models for BF%		B	Std Error B	Standardised β	*p-value*	95% CI
1	**(Constant)**	25.8	3.13		<0.01	19.5, 32.1
	Rigid Restraint	0.73	1.02	0.13	0.48	-1.32, 2.78
	Flexible Restraint	0.6	1.13	0.09	0.6	-1.66, 2.86
	Habitual Disinhibition	2.42	1.43	0.24	0.1	-0.44, 5.27
	Emotional Disinhibition	-1.21	1.15	-0.13	0.3	-3.51, 1.1
	Situational Disinhibition	-0.42	1.09	-0.06	0.7	-2.61, 1.77
	Internal Hunger	1.71	1.27	0.2	0.18	-0.83, 4.26
	External Hunger	-4.13	1.73	-0.4	0.02	-7.59, -0.68
F= 2.76, R2 adjusted= 0.153, *p-value*= 0.015						
2	**(Constant)**	10.5	7.38		0.16	-4.26, 25.3
	Rigid Restraint	0.17	0.92	0.03	0.85	-1.66, 2
	Flexible Restraint	0.91	0.99	0.14	0.36	-1.08, 2.9
	Habitual Disinhibition	1.8	1.26	0.18	0.16	-0.71, 4.31
	Emotional Disinhibition	-1.44	1.05	-0.16	0.17	-3.54, 0.66
	Situational Disinhibition	-0.07	0.99	-0.01	0.94	-2.05, 1.91
	Internal Hunger	1.36	1.12	0.16	0.23	-0.89, 3.6
	External Hunger	-2.09	1.58	-0.2	0.19	-5.25, 1.06
	Gender	11.1	2.46	0.49	<0.01	6.14, 15.9
	Age	-0.14	0.14	-0.11	0.32	-0.43, 0.14
F= 5.1, R2 adjusted= 0.352, *p-value*= <0.001						

Appendix B9. *Multiple Linear Regression for Muscle Mass Correlating to TFEQ Sub-Factors*

Models for Muscle mass		B	Std Error B	Standardised β	*p-value*	95% CI
1	(Constant)	31.5	2.41		<0.01	26.6, 36.3
	Rigid Restraint	-0.73	0.79	-0.17	0.36	-2.3, 0.85
	Flexible Restraint	-0.56	0.87	-0.12	0.52	-2.3, 1.18
	Habitual Disinhibition	-0.65	1.1	-0.08	0.56	-2.85, 1.55
	Emotional Disinhibition	-0.13	0.89	-0.02	0.88	-1.91, 1.65
	Situational Disinhibition	0.93	0.84	0.17	0.27	-0.76, 2.62
	Internal Hunger	-0.71	0.98	-0.11	0.48	-2.67, 1.26
	External Hunger	2.4	1.33	0.31	0.08	-0.26, 5.06
F= 2.211, R2 adjusted= 0.111, *p-value*= 0.045						
2	(Constant)	54.2	4.46		<0.01	45.3, 63.1
	Rigid Restraint	-0.26	0.55	-0.06	0.64	-1.37, 0.85
	Flexible Restraint	-0.86	0.6	-0.18	0.16	-2.06, 0.34
	Habitual Disinhibition	0.04	0.76	<0.01	0.96	-1.48, 1.56
	Emotional Disinhibition	0.41	0.63	0.06	0.52	-0.86, 1.68
	Situational Disinhibition	0.31	0.6	0.06	0.6	-0.88, 1.51
	Internal Hunger	-0.41	0.68	-0.06	0.55	1.76, 0.95
	External Hunger	0.21	0.95	0.03	0.83	-1.7, 2.11
	Gender	-12.5	1.49	-0.74	<0.01	-15.5, -9.52
	Age	0.02	0.09	0.02	0.85	-0.16, 0.19
F= 11.521, R2 adjusted= 0.582, *p-value*= <0.001						

Appendix B10. *Multiple Linear Regression for Diet Duration Correlated to BMI*

Models for BMI		B	Std Error B	Standardised β	*p-value*	95% CI
1	**(Constant)**	26.9	0.74		<0.01	25.4, 28.5
	Diet Duration	-0.07	0.02	-0.29	<0.01	-0.12, -0.04
F= 5.881, R2 adjusted= 0.07, *p-value*= 0.018						
2	**(Constant)**	30.1	<0.01		<0.01	25.2, 35.5
	Diet Duration	-0.07	<-0.02	-0.27	<0.01	-0.11, -0.04
	Gender	-0.31	<-0.01	-0.03	0.76	-2.18, 1.57
	Age	-0.08	<0.01	-0.13	0.27	-0.22, 0.06
F= 2.391, R2 adjusted= 0.08, *p-value*= 0.077						

Appendix B11. *Multiple Linear Regression for Diet Duration Correlated to Habitual Disinhibition*

Models for Habitual Disinhibition		**B**	**Std Error B**	**Standardised β**	***p-value***	**95% CI**
1	**(Constant)**	1.2	0.17		<0.01	0.89, 1.53
	Diet Duration	-0.02	<0.01	-0.29	<0.01	-0.03, -0.01
F= 5.919, R2 adjusted= 0.07, *p-value*= 0.018						
2	**(Constant)**	1.28	0.68		0.06	-0.17, 2.6
	Diet Duration	-0.02	<0.01	-0.27	<0.01	-0.03, -0.01
	Gender	0.29	0.24	-0.13	0.22	-0.18, 0.75
	Age	-0.02	0.02	-0.13	0.39	-0.06, 0.02
F= 2.663, R2 adjusted= 0.071, *p-value*= 0.056						

Appendix B12. *Multiple Linear Regression for Diet Duration Correlated to Waist Circumference (WC)*

Models for WC		B	Std Error B	Standardised β	*p-value*	95% CI
1	**(Constant)**	80.9	1.7		<0.01	77.7, 84.4
	Diet Duration	-0.15	0.06	-0.25	<0.01	-0.28, -0.04
F= 4.41, R2 adjusted= 0.05, *p-value*= 0.04						
2	**(Constant)**	96.3	5.76		<0.01	85.1, 107
	Diet Duration	-0.16	0.06	-0.26	0.01	-0.29, -0.06
	Gender	-8.35	2.27	-0.37	<0.01	-12.7, -3.74
	Age	-0.02	0.16	-0.02	0.87	-0.35, 0.29
F= 5.18, R2 adjusted= 0.162, *p-value*= 0.003						